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3 STERILIZABLE ACCELEROMETER H

~~THIRD~~ 4 QUARTERLY TECHNICAL REPORT

29B

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25A 25b

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ABSTRACT

Work on the mechanical assembly was concentrated on the improvement of the bond from the springs to the pendulum supports and on evaluation of non-metallic sterilizable materials selected from JPL Spec. WR500304.

Accelerometer M-225 was provided with Scotchcast EC-2258 in the spring joints. The experimentation program was not completed. Failure of Formex insulated magnet wire in the torquer coil required rebuilding of the accelerometer.

Non-metallic materials under investigation, besides Formex insulation, were Epon 828 Z, Mystik tapes 7352 and 7300 and Kynar shrinkable tubing.

First attempts at laser welding on the pendulum assembly, however not on the spring joints, were made.

Emphasis was placed on the pickoff electronics in the area of the bridge pickoff transformer. A study was conducted in the area of transformer parts such as core-tapes, wire, etc., to insure proper operation after temperature sterilization.

Discrete components intended for use in the final electronic assemblies were selected, using JPL approved parts where possible or at the very minimum manufacturer equivalent parts. A complete Design Review of the electronic subassembly was conducted and is presented in this report.

1. MECHANICAL ASSEMBLY

The main purpose of the investigation is twofold; first, to reduce the adverse effects of temperature sterilization on the bias stability of the accelerometer. Second, to avoid the appearance of the white opaque granular deposit in the airgap of the accelerometer, a deposit, which has been observed on the two accelerometers so far submitted to the temperature sterilization environment of 275°F for 360 hours.

The main cause for the deterioration of the bias stability is seen in the effects of temperature sterilization on the joints from the spring tabs to the pendulum supports. In standard Model VII accelerometers, the LCA-4 epoxy is used in the said joints. These accelerometers show considerable deterioration of bias stability after being submitted to a temperature environment far less severe than that of temperature sterilization. It is felt that the Ablecast 147-1 epoxy, which was evaluated during the previous quarterly report period, represents an improvement over the LCA-4 epoxy; it does, however, not meet the stability requirements of this program. For this reason, the search for a better adhesive has been continued during the present report period. This search, described in Section 1.1, still involves two phases: pre-evaluation of epoxies by shear test, and evaluation in a functional accelerometer. First experiments with laser welding as an alternate approach to perfecting the said joint have been made in the pendulum-support-to-coil form area. They are described in Section 1.3 of this report.

The actual source of the white opaque granular deposit in the airgap has not been definitely identified. The FFA-2 epoxy used in standard accelerometers to make the torquer coils is still the prime suspect among the other non-metallic components. Replacements for non-metallic materials having better chances to withstand temperature sterilization have been selected for experimentation. It is felt to be important that all of these materials should be applied in an accelerometer during an experiment intended to demonstrate that the white opaque granular deposit has been eliminated. The experiment is performed on accelerometer M-225 and combined with the evaluation of the bonding material in the spring to support joints performed in this unit. One of the substitute materials, namely, Kynar shrinkable tubing, has been experimented on separately as reported in Section 1.2.4.

1.1 Adhesive Spring-to-Support Bond

1.1.1 Shear Tests

The hardware used and methods of evaluation applied have been described in Section 1.1.2 of the previous quarterly technical report.

Following up on a recommendation by Emerson and Cummings, four test specimens were made with the 2850 FT/11 epoxy as a backup for the Scotchweld EC-2258 epoxy in case of an early failure of this epoxy.

In addition, four test specimens were made with the LCA-4/BA-9 epoxy which is currently used in standard Model VII accelerometers. The purpose here is to supply reference data.

Two of each type of test specimens were exposed to a temperature of 275°F for 360 hours and then submitted to shear test, together with the samples that had not been sterilized.

The results of the shear tests are listed in Table I, Page 5. These results may be compared with these obtained with Bondmaster BU-120 D, Ablecast 147-1 and Scotchweld EC-2258, all listed in Table I, Page 7 of the previous quarterly technical progress report. The rupture stress of the 2850 FT/11 epoxy can be considered average before temperature sterilization. After temperature sterilization it retains only 30% of its initial rupture stress. The rupture stress of the LCA-4, which is reduced by about 50% through temperature sterilization, is considered to be more on the high side both before and after temperature sterilization.

In all specimens of the 2850 FT/11 epoxy, it was found that separation occurred either on the aluminum surface or on the Berylco 25 surface, but not parallel to these surfaces through the bonding material. This was also the case in the LCA-4/BA-9 specimens after temperature sterilization. Before temperature sterilization shearing in the LCA-4/BA-9 specimens took place mainly in the epoxy layer. The criterion of the percentage of adhesive remaining attached to the Berylco 25 material does not apply here. In all other cases, this percentage is again indicated. The special behavior of the LCA-4 epoxy before temperature sterilization may in part explain the success with which this material has been used in standard accelerometers not required to meet the temperature sterilization environment.

As mentioned in the previous quarterly technical report, the open ends of the slots of the aluminum parts were found widened by about .010 inch after shear test in the samples made with the EC-2258 epoxy. Nothing similar was observed on occasion of the tests performed on the 2850 FT/11 and LCA-4/BA-9 epoxies.

ADHESIVE	SPECIMEN NO.	TEMPERATURE STERILIZED	RUPTURE LOAD LBS.	RUPTURE STRESS LBS. PER IN^2	PERCENTAGE OF ADHESIVE REMAINING ON BERYLCO 25 SURFACE (BY SIDES)	
					SIDE A	SIDE B
2850 FT/11	13	No	510	2550	100	70
Emerson and Cummings	14	No	600	2885	20	80
	15	Yes	155	745	0	0
	16	Yes	165	842	0	0
LCA-4/BA-9	17	No	775	4120	Not Appl.	Not Appl.
Ablestik Adhesive Company	18	No	480	3085	Not Appl.	Not Appl.
	19	Yes	410	2091	5	5
	20	Yes	290	1450	0	0

TABLE 1. SHEAR TEST RESULTS

1.1.2 EC-2258 Epoxy in Functional Accelerometer

As a result of the pre-evaluation of adhesives described in detail in Section 1.1 of the previous quarterly technical report, the adhesive Scotchweld EC-2258 (also referred to as PA-2258) was chosen as the material to be next investigated in application to the bond from the spring tabs to the support of a functional accelerometer. Unit M-225 was accordingly rebuilt. Some difficulties were encountered during the process. The first attempt to produce the joints failed. The liquid tension of the epoxy had pulled the spring tabs to one side in the slots. This condition was detected before the epoxy was fully cured and it was possible to remove the epoxy mechanically without damaging the pendulum supports. The operation was repeated while precautions were taken to avoid deflection of the spring tabs. These efforts were successful. However, after the curing of the EC-2258 epoxy, the torquer coil was partly shorted out as indicated by a change of resistance from 14 ohms before curing to about 6 ohms after curing. (The windings that had failed were insulated with Formex. For reference see section 1.2.1 of this report). The accelerometer had to be rebuilt and the established technique for the application of the EC-2258 epoxy again proved successful.

After going through the standard preliminary tests, accelerometer M-225 was submitted to two temperature runs and to a complete series of flip-flop soaks.

During each temperature run, reference values were established at room temperature; then the instrument was heated up to about 125°F and allowed to stabilize at this temperature for about 5 hours. Return point readings were taken at room temperature, after stabilization. The results are listed in Table II.

TABLE II.

VARIATION OF BIAS WITH TEMPERATURE IN UNIT M-225

CONDITION	TEMPERATURE °F	BIAS, µg	SLOPE, µg/°F
Start	75	-286	
			-4.13
High	127	-501	
			-.47
Return	73.4	-476	
Start	73.5	-473	
			-.77
High	125.5	-513	
			-3.19
Return	72.8	-345	

For the intervals from start to high and from high to return the average change of bias with temperature has been computed. The resulting slope values are entered in the right hand column of Table II. It will be noticed that these slope values vary heavily, which fact is found to be due to the rather large spread of bias values at room temperature; the bias repeatability at the elevated temperature is quite good. The average slope of -2.14 ug per °F is considered good performance.

The procedure involved in the flip-flop soak tests has been described in section 1.2.1 of the previous quarterly technical report. As stated, these tests are applied before and after temperature sterilization to determine the effect of temperature sterilization on the null stability of the accelerometer. The flip-flop soaks reported on below are those performed prior to the temperature sterilization. The results are contained in Table III.

TABLE III.

FLIP-FLOP SOAK TEST RESULTS

	BIAS IN ug
Before the first "Flip" soak	-351
After the first "Flip" soak	-591
After the first "Flop" soak	-407
After the second "Flip" soak	-487
After the second "Flop" soak	-157
After the third "Flip" soak	-449
After the third "Flop" soak	-203

The above listed bias values are entered in the graph page 9. The line connecting the points emerges, as expected, as a saw-tooth diagram. This diagram may be compared to that obtained with the Ablecast 147-1 epoxy; the latter may be found on page 16 of the previous quarterly technical report. The corresponding part of this graph is designated as "First Series of Flip-Flop Soaks" (November 1966). Besides showing a broader bandwidth, the saw-tooth diagram obtained with the EC-2258 epoxy appears more irregular than that obtained with the Ablecast 147-1 epoxy. The final evaluation of the EC-2258

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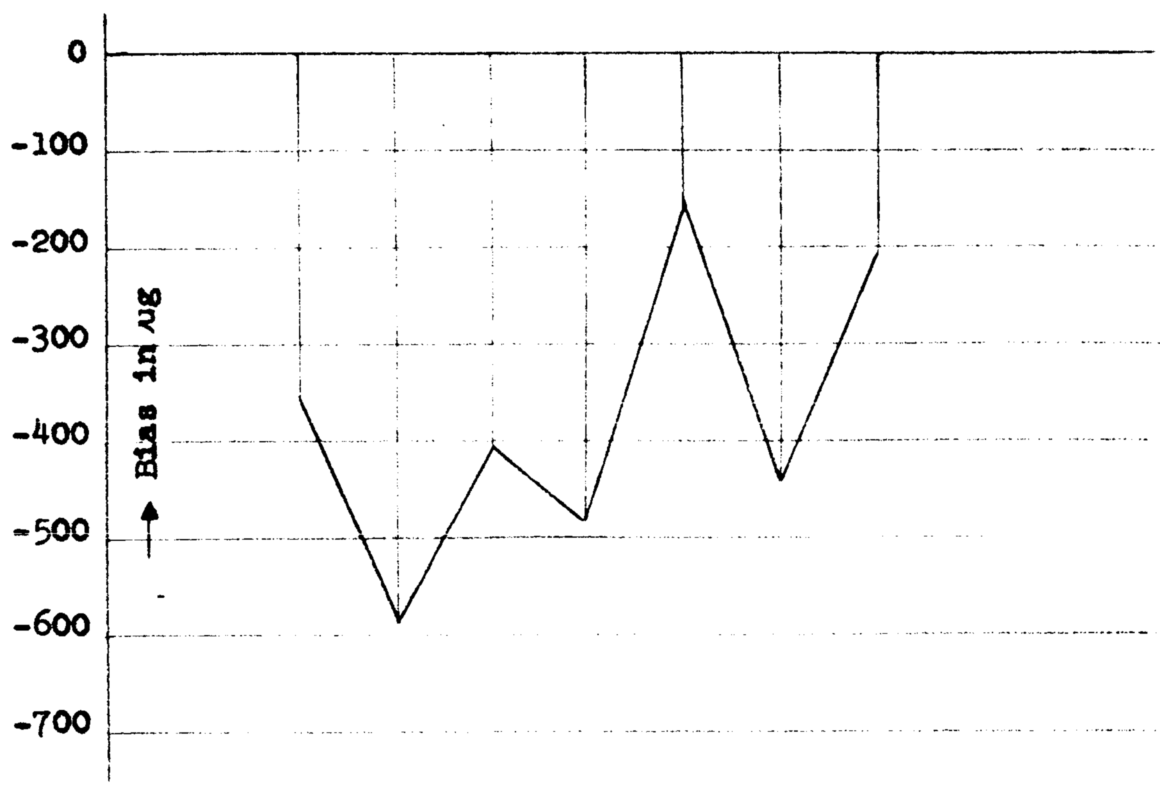
FLIP-FLOP SOAK RETURN POINTS

APRIL 1967

EPOXY IN SPRING TO SUPPORT JOINTS SCOTCHWELD EC-2258

(BEFORE TEMPERATURE STERILIZATION)



epoxy will depend upon whether or not the bandwidth increases and eventually how much it increases after temperature sterilization. The corresponding experimentation is planned for the next quarterly reporting period.

1.2 Balance of Non-Metallic Materials

The main work in the area of non-metallic materials concerns the replacement of questionable or objectional materials by materials listed in JPL Spec. WR500304. This work has not progressed in all areas as expected because it is tied in with the experimentation performed on accelerometer M-225 and this experimental program suffered a set-back. Some progress was made where the investigation was carried out on separate subassemblies. The corresponding situation will be stated in each of the subsequent sections.

1.2.1 Formex (GE) Insulated Magnet Wire

As projected in the previous quarterly technical report (see section 2.2, page 21, under the heading "Isonel Wire Type 155"), the pendulum of accelerometer M-225 was supplied with a torquer coil wound with Formex insulated magnet wire in replacement of the formerly used heavy Isonel type 155 magnet wire. The latter is rated at 135°C by the manufacturer, which is marginal.

For the cure of the epoxy used to connect the spring tabs to the pendulum supports, the Scotchweld EC-2258, one hour at 350°F is recommended by the manufacturer. The entire pendulum subassembly is subjected to this environment. After this cure, the torquer coil winding was found to be partly shorted out as already reported. The resistance had dropped from 14 ohms to 6 ohms. It was then decided to rebuild the pendulum assembly with heavy Isonel type 200 magnet wire which is rated at 185°C by the manufacturer..

Because a coil form with outer rim is used, the pendulum supports had to be removed for rewinding of the coil; they were replaced by new parts. The pendulum assembly was rebuilt with Scotchweld EC-2258 which again was cured for 1 (one) hours at 350°F. This time no adverse effects were noticed. The accelerometer was then reassembled and it performed normally in test.

1.2.2 Epon 828 Z Epoxy

Efforts are underway to replace the Epon 828 D epoxy by the Epon 828 Z epoxy which is listed as one of the preferred non-metallic materials in JPL Spec. WR-500304. The Epon 828 D is used for two purposes in standard Model VII accelerometers; first, to attach the Diamonite spring insulators to the base plate and to the spring clamps; second, to bond the flux path plates to the tops of the magnets.

During the latest rebuilding of accelerometer M-225, the Epon 828 Z has been accordingly used. A curing cycle of two hours at 200°F followed by two hours at 275°F was applied.

Because the accelerometer M-225 has not been subjected to temperature sterilization after this rebuilding, no definite conclusion has yet been reached. However, it can be stated that no difficulties were encountered during the rebuilding stage. It appears especially significant, that the epoxy bond withstood the grinding operation performed on the Diamonite insulators. As pointed out on page 17 of the first quarterly technical report, this grinding operation produces the heaviest stress that this bond has to withstand.

As shown by the temperature runs mentioned in section 1.1.2 of this report, the bias stability of the accelerometer in the environment of changing temperatures does not appear to have been impaired by the change to Epon 828 Z. The effects of temperature sterilization are to be evaluated during the next quarterly reporting period.

Apart of the efforts to replace the Epon 828 D by Epon 828 Z, experiments were conducted to replace the Tuf-on used to cover the bare magnet surfaces by Epon 828 Z. Because of the difficulties encountered in the experimentation with accelerometer M-225, two separate magnet assemblies were set aside for the tests involved.

A thin film of 828 Z was applied to the bare magnet surfaces and cured using the cycle described above. The magnet assemblies were then subjected to a temperature sterilization cycle of 360 hours at 275°F. Upon removal from the oven, the film of Epon 828 Z was found to be discolored to a brownish hue, however, it did not show any tendency to separate from the magnet surfaces. When originally applied to these surfaces, the epoxy had been clear and it was then hard to see if all bare areas were covered. The discoloration showed that this was not the case; some patches had remained bare. It appears that a material with a better wetting action would be preferable to the Epon 828 Z. As long as such a material has not been identified, it is planned to apply the Epon 828 Z if the magnet surfaces of the deliverable accelerometer show pinholes or cracks. As pointed out in section 2.2 of the previous quarterly report under the heading "Tuf-on 747-S", the magnets of accelerometer M-225 did not show such defects and their surfaces were left bare.

1.2.3 Tapes

During the previous quarterly reporting period two types of tape were under evaluation, namely the Mystik tape 7352 as a replacement for the 3M #5 electrical tape and the Mystik tape 7300 as a replacement for the 3M #55 electrical tape. Both of the Mystik tapes are listed as preferred non-metallic materials in JPL Spec. WR-500304.

As stated in section 3, page 22 of the previous quarterly technical report, these tests were not considered conclusive and repetition of the tests was planned for the present quarterly reporting period. Accelerometer M-225 was accordingly rebuilt with both of the types of Mystik tape applied.

Due to the setback in the rebuilding program of accelerometer M-225 reported above, this unit has not yet been subjected to temperature sterilization after its latest rebuilding. Final results are, however, expected early in the next quarterly reporting period.

1.2.4 Kynar Tubing

In standard Model VII accelerometers, Rayclad RNF-100 heat shrinkable tubing is used to relieve stresses in the capacitance leads where they connect to the capacitance rings. The leads are soldered into small brass tubes protruding from the capacitance rings. The isolation on the leads butts up against the tubes. A short piece of tubing is shrunk over the brass tubes and the adjacent part of the capacitance lead insulation.

An experiment was conducted to replace the RNF-100 tubing by Rayclad Kynar shrinkable tubing which is listed in JPL Spec. 500304 as a preferred non-metallic material. Because of the difficulties encountered with the rebuilding of accelerometer M-225, it was decided to conduct this experiment on a separate magnet housing containing a capacitance ring. The shrinking of the Kynar tubing required a slightly higher temperature than that currently applied to the RNF-100 tubing, but no basic difficulties were encountered. The magnet housing was subjected to a temperature of 275°F for 360 hours. Inspection then showed the Kynar tubing to be completely unchanged. It is suggested to apply this material in the deliverable accelerometer.

1.3 Laser Welding

For reference see Bell Report Number 60002-440-1, Supplement Number 1 "Proposal for Design of a Sterilizable Accelrometer", Appendix 2, Page 13.

The ultimate goal of the application of laser welding in the development of a sterilizable accelerometer is the bonding of the spring tabs to the supports. This contract provides only for preliminary investigations.

As a first step in gaining experience with the technique involved, some laser welding was performed at the Marshall Space Flight Center on aluminum parts. These parts, namely the pendulum coil form and the pendulum supports, were chosen because the welding could be performed with available fixturing. Furthermore, the elimination of an epoxy bond was kept in mind.

Each pendulum support is provided with two prongs that are riveted into holes in the coilform. In standard Model VII accelerometers the connection between the coilform and each support is reinforced by epoxy applied to the seams at the junction of the supports and the coilform. This epoxy was not applied in the samples intended for the experimentation with laser welding. Instead, spot welding was performed on both sides of each support where the supports and the coilform come together. The subassembly consisting of the coilform and the riveted supports was placed on an arbor otherwise used for coil winding. On this arbor, the coilform is held in place between a shoulder on the arbor and a button tightened by a screw. The arbor carrying the pendulum subassembly was placed on a V-block in the position indicated in figure 1M. The laser beam was aimed as shown for welding of the first set of spots. The remaining weld spots were obtained by turning the arbor in the appropriate positions in which the arrows indicating the position of the weld spots in figure 1M were aligned with the laser beam. In figure 1M the button and the screw securing the pendulum subassembly are not shown.

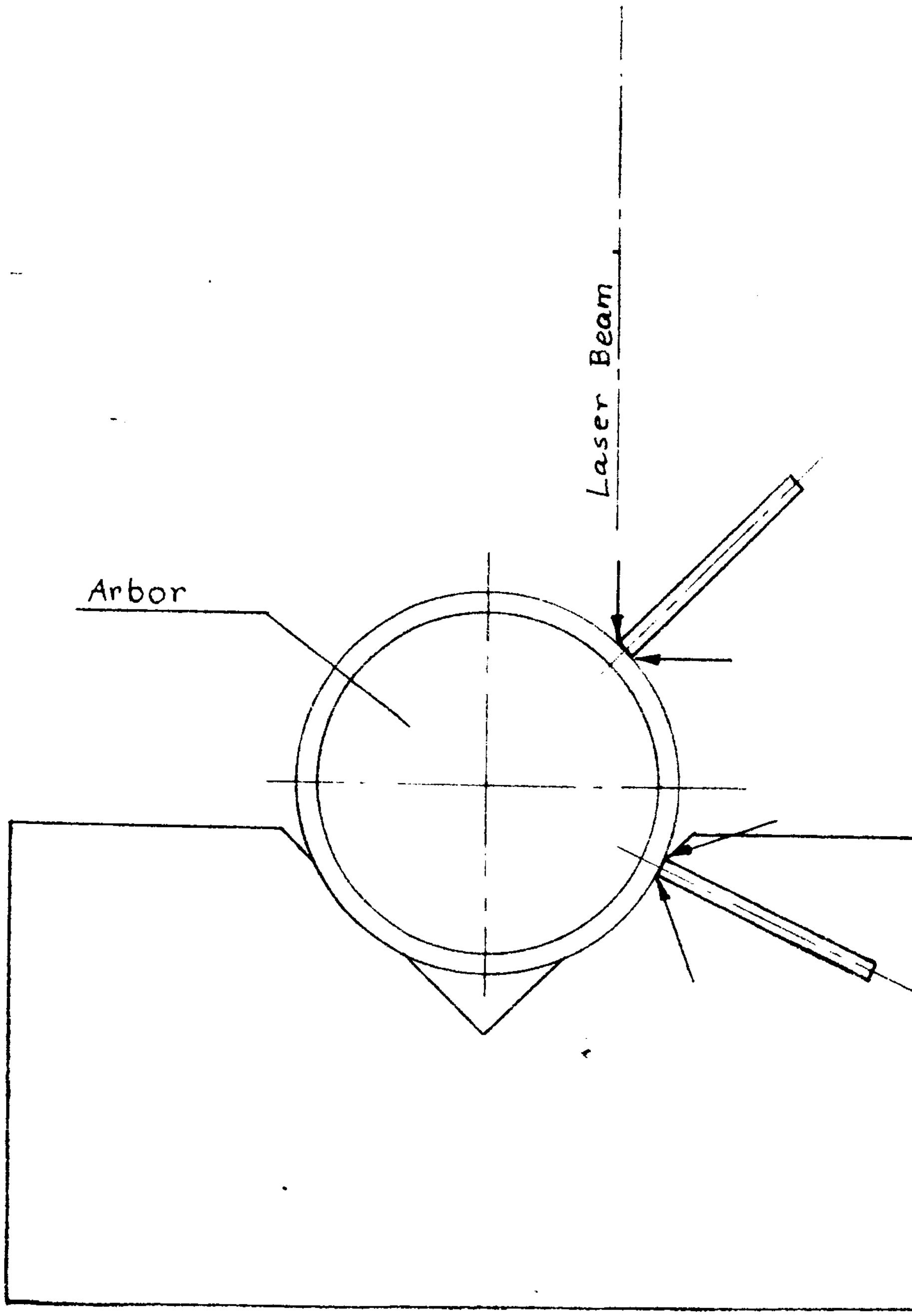


Fig. 1M. Welding of Supports to Coilform

Four arrows indicate locations of weld spots

Before experimenting with welding on the pendulum subassemblies, a schedule was established to butt weld aluminum sheet of a thickness of .020" which comes close to the thickness of the coilform which is .019" and to that of the supports which measure about .016" in thickness. The type of aluminum alloy used has properties close to those of the aluminum alloy 3003 which is used to make the supports.

The schedule giving best results was as follows: a pulse time of 5 milli seconds, a weld diameter of ..020 inch. The voltage was varied between 1475 and 1550 volts.. The laser welder is of the type Westinghouse LMT-21.

The above schedule was applied to the junction of the supports to the coilform. It was observed that the weld quality looked good where the two parts to be welded came in direct contact with one another at the point to be welded. Very small gaps still could be bridged, but gaps of a few thousands of an inch very much reduced the quality of the weld. In case of larger gaps, the two parts did not connect. These observations indicate the need for a design change if it should be decided to apply laser welding to the pendulum subassembly. At present, the supports are punched out of flat stock; on one side the edges are sharp, on the other side they are rounded off. The shoulders adjacent to the coil form would have to be machined in a manner making both edges sharp for proper laser welding.

A further observation made concerns the impact of the laser beam on the parts to be welded; this impact is felt to be quite appreciable, which would be an important factor in the laser welding of the spring tabs.

Before being able to conclude definitely on the applicability of laser welding to the joining of the spring tabs to the pendulum supports in functional accelerometers, extensive fixturing and experimenting exceeding the scope of this contract would have to be performed. The fixturing would have to allow alignment of the spring tabs with the mating parts of the pendulum supports leaving a gap of only fractions of a thousands of an inch. In addition, provisions would have to be made to support the spring tabs in direction of the sensitive axis to prevent damage to the working area through the impact of the laser beams on the spring tabs. The need for heat sinks applied to the spring tabs, protecting the spring working area against adverse effects of the welding heat would have to be investigated.

2. ELECTRONIC ASSEMBLY REVIEW

2.1 Design Review (Introduction)

This pre-production design report is submitted to Jet Propulsion Laboratory to furnish a description of the Bell design proposed to meet the requirements of JPL Sterilization Contract #951492.

Where possible, it has been attempted to fulfill the requirements for this design. However, due to the fact that the program is presently in only the pre-production stage, very little test data, etc. is available for inclusion with the report.

Since the JPL Sterilizable Model VIIB-16 accelerometer (Part No. 26-01290-1) is basically an adaptation of the standard Model VII accelerometer, this design report mainly covers the areas which required re-design in order to meet JPL Sterilization Requirements.

2.1.1 Electronic Design

The pre-amplifier for the Model VIIB-16 accelerometer has been re-designed to meet the requirements of JPL Specification. The re-design includes the pickoff transformer as well as the pre-amplifier. The complete electronic subassembly will be referred to as the bonnet. This connotation is Bell nomenclature which is a carry-over from other similar programs.

The bonnet consists of the following: the upper half fixed bridge capacitors, the pickoff transformer and the preamplifier. These components are housed between two printed circuit boards which are physically anchored to the upper cover.

When attached to the accelerometer, the specification can be evaluated on a black box approach which includes the following parameters:

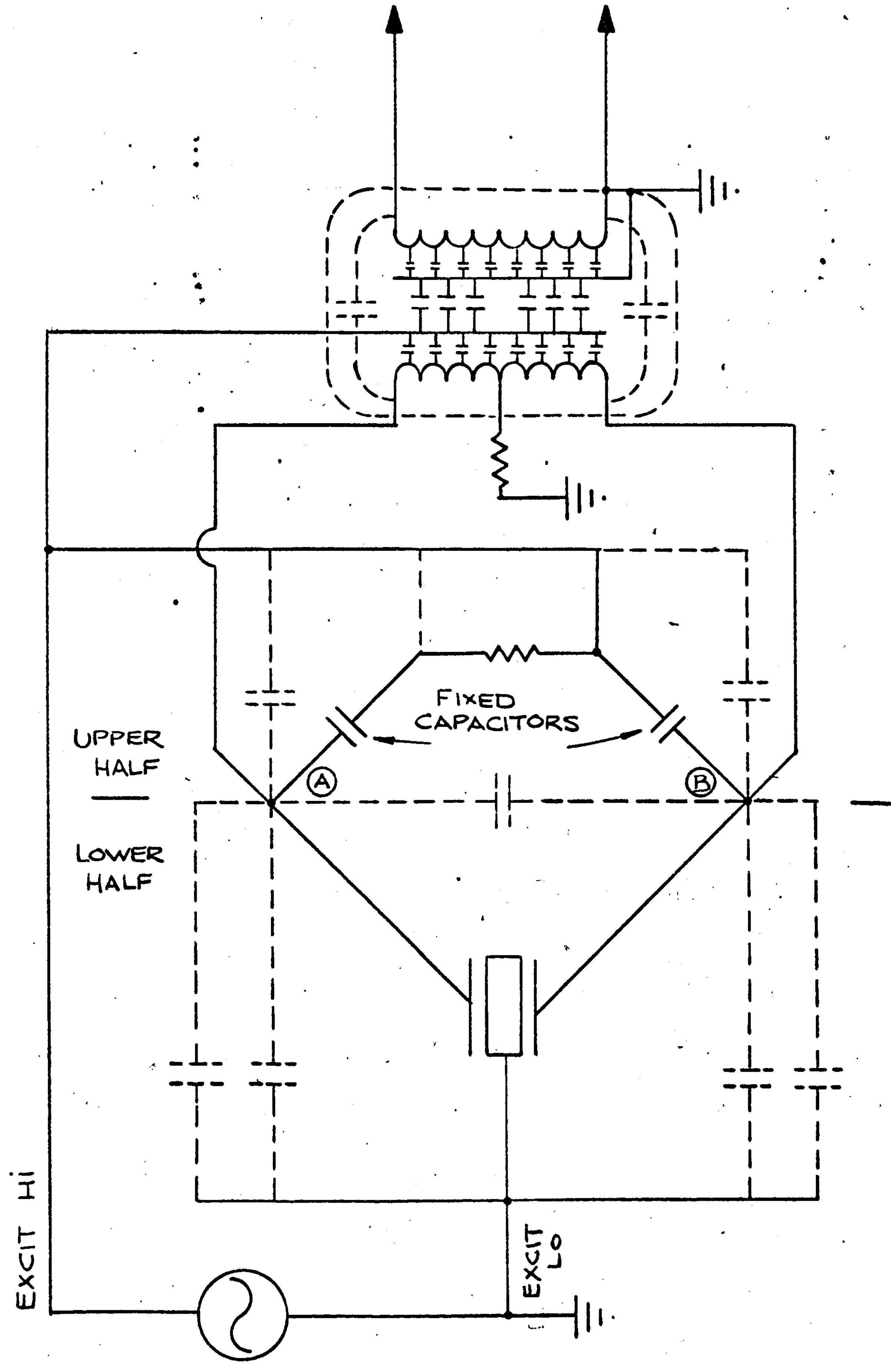
Input Impedance:	$-j$ 8.0K Ohm or greater
Pickoff Sensitivity (output sensitivity):	40 ±5 mv./mr.
Phase Angle: $90^\circ \pm 10^\circ$	heading with header pin "H" down
Maximum Power Consumption:	<.125 Watts
Noise:	<1.0 mv
Output Impedance:	< 500 ohms
Quadrature:	<1 mv.

The design as described in the succeeding sections is based on meeting the requirements of JPL Specification #951492.

2.1.2 Balanced Bridge Circuit

The balanced bridge circuit consists of two discrete components (fixed capacitors) in the upper arm of the capacitance bridge. The lower half consists of two mechanical type capacitance rings spaced equidistant from the pendulum assembly which acts as the center rotor of a variable differential capacitor. Deflection of the pendulum assembly causes an unbalance in the capacitive bridge, and an error voltage is developed across points A and B. (See Figure 1E) This voltage is amplified by the preamplifier which will be discussed later in this text.

Care must be used and taken in the design of the pickoff circuitry, in that stray capacities cause undesirable and unpredictable effects. The design tends to minimize stray capacity effects, wherever possible. In areas where strays are present symmetry is stressed. Capacitors (fixed) are chosen which have very close tracking characteristics, particularly in temperature coefficients. (See Figure 1E)



BALANCED BRIDGE CIRCUIT

FIGURE 1E

2.1.3 Pickoff Transformer

The transformer is designed to pick off the error signal from the balanced bridge circuit and couple it into the preamplifier. Unlike most audio frequency transformers, the stray capacities have a heavy influence on the performance of the balanced bridge circuit, this transformer requires shielding on both primary and secondary. Operating the transformer at resonance also makes stray capacities from primary to secondary a problem; here again the shield tends to eliminate this condition. It can be shown that the capacities which exist between primary and shield fall across the top half of the balanced bridge. This is done purposely in that these stray contributions can be more readily handled in the bonnet assembly. They also reduce the generator driving source impedance. The capacities which exist between primary and secondary shield fall across the driving generator, and in no way influence bonnet performance; it does, however, influence input impedance:

C_B = Equivalent capacities of the balanced bridge.

C_{ps} = Capacities which exist between primary and secondary shield.

$$\text{Input Impedance} = \frac{1}{2\pi FC} = \frac{1}{2\pi\, 192 \times 10^3 \times (C_B + C_{ps})}$$

$$\text{where } C_B \cong 22 \text{ pf}$$

$$C_{ps} \cong 70 \text{ pf}$$

Input Impedance $\approx \dfrac{1}{6.28 \times 192 \times 10^3 \times 92 \times 10^{-12}}$

Input Impedance $\cong \dfrac{.159}{17.6 \times 10^{-6}}$

Input Impedance $\cong \dfrac{.159}{.176 \times 10^{-4}} = .9034 \times 10^4$

Input Impedance $\cong$ 9.0 K ohms

There still exists two capacities which fall across the secondary of the transformer. These capacities do influence performance in that the reflected capacities as seen on the primary sides of the transformer are reflected by the reciprocal of the turns ratio squared of the transformer, however they do not influence bridge unbalance.

Capacitance, on the secondary as seen in the primary circuit

Primary reflected = Capacitanse secondary $\times \dfrac{1}{N^2}$

where $N = 2.0$

$N^2 = 4.0$

Assume a capacity of 100 pf across the secondary,

Capacitance reflected $= \dfrac{100 \text{ pf}}{4} = 25$ pf.

As evidenced above, the capacity changes in the secondary circuitry have some effect in circuit performance, particularly the resonant frequency of the bridge transformer. Parameters which influence the resonant frequency of the transformer are:

The equivalent bridge capacity as seen across the primary of the transformer, the distributed capacity across the primary of the transformer (due to winding) and the stray capacities which appear across the primary. As shown before, the secondary capacities have significant effect, however, by adjusting the secondary capacity via a fixed value capacitor, a fine tune on resonance can be accomplished.

$$F = \frac{1}{2\pi\sqrt{LC}}$$

$Fr = 192.0$ KC

$L = 12$ mh.

Cap, Bridge $\cong$ 15 pf

Distributed Cap. $\cong$ 20 pf

Where C = (Bridge capacity + Distributed + Reflected)

$$Fr = \frac{1}{2\pi\sqrt{LC}}$$

$$\sqrt{LC} = \frac{1}{2\pi F}$$

$$LC = \left(\frac{1}{2\pi F}\right)^2$$

$$LC = \left(\frac{.159}{.193 \times 10^{+6}}\right)^2 = \left(.828 \times 10^{-6}\right)^2$$

$$LC = \left(8.28 \times 10^{-7}\right)^2 = 68.55 \times 10^{-14}$$

$$C = \frac{68.55 \times 10^{-14}}{12 \times 10^{-3} \text{ henrys}} = 5.71 \times 10^{-11}$$

$$\boxed{C = 57 \times 10^{-12} \text{ farads}}$$

Since the equivalent bridge capacity $\cong$ 22 pf.

and the distributed primary capacity $\cong$ 13 pf.

The total tune capacity available from the combination of fixed and distributed = 35 pf.

As shown above a minimum of 57 pf is required to tune to 192 KC. The additional tune capacity is inserted in the circuit (as a selected item) to tune the primary to 192 KC; this capacity is nominally 50 pf.

It should be pointed out that the circuit is designed such that it always requires a secondary capacitor in order to tune to resonance 192 KC.

Figures 2E through 13E show typical construction of the pickoff transformer.

Another unique feature of this particular transformer design is its center tap primary. The center tap is incorporated to accommodate a single bleeder resistor rather than a bleeder resistor from each capacitance ring to ground. A study was conducted to determine the differential aging effect of the two bleeder resistor design; it showed that bias could be affected under certain conditions of resistance tracking. The study was conducted using frequencies much lower than the excitation frequency for this program; it did, however, show that the higher the frequency the lower the effect on null bias.

Because of this study, it was decided to incorporate a single bleeder resistor from a center tapped transformer to ground. See Figure 16 SCHEMATIC DIAGRAM. This is added assurance the bias will not be affected because of the presence of the bleeder resistor.

Potting Compound

The potting compound selected to encapsulate the bridge pickoff transformer is STYCAST 2850 FT catalyst #11. It is classified as a hi Thermal conductivity costing resin which will stand temperatures in the range of 400°F and greater. The manufacturer is Emerson and Cumming.

The potting compound appears on the JPL Spec. WR-500304, Titled, Polymeric and Other Nonmetallic Materials, preferred Mariner Mars 69 Spacecraft, General Requirements for. It does, however, appear with the catalyst #9 callout. The manufacturer was contacted by phone in February 1967 in search of more detailed information on the 2850 FT/R11, R2, R4, R5, as well as 2651 MM/11 which had previously been used to encapsulate bridge transformers in house. A comparative chart is included in this report. (See Table I), along with complete manufacturers data sheets. Technical Bulletin #7-2-10A STYCAST 2655MM and Technical Bulletin #7-2-7A STYCAST 2850FT. Of all the parameters, the Dielectric Constant is of utmost importance, in that as it goes up, so does the capacitance drifts of the bonnet go up, because of any unsymmetrical stray capacitors in the transformer due to potting.

Care has been taken to insure symmetry, both in the transformer, as well as the bonnet layout so it is felt even though the Dielectric Constant of 2250FT is high, the performance will not be significantly changed because of the symmetry involved, as one side to ground or excitation hi changes, so will the other change proportionally.

TABLE I

	LOW EXPANSION High Thermal Conductivity		GENERAL PURPOSE ENCAPSULANTS	
	STYCAST® 2850-FT	STYCAST® 2850-GT	STYCAST® 2651	STYCAST® 2651-MM
	HIGHEST THERMAL K LOW SHRINK	HIGH THERMAL K BEST RIGID THERMAL SHOCK	LOW COST VERSATILE QPL 16923	LOW COST GOOD FLOW
Basic Composition	Filled Epoxies			Filled Epoxies
Mix Preparation	Add Catalyst 9, 11 or 24-LV	Add Cat. 9 or 11		Add Cat. 9 or 11
	TYPICAL PROPERTIES	TYPICAL PROPERTIES	TYPICAL PROPERTIES	TYPICAL PROPERTIES
Mixed Viscosity centipoises	70,000	100,000	25,000	6000
CURE TEMPERATURE	R.T. or Elev.	R.T. or Elev.	R.T. or Elev.	R.T. or Elev.
Curing Shrinkage (average) in/in	.001	.001	.002	.002
CURED PROPERTIES				
Standard Color (see Note 1.)	Black	Black	Black	Black
Flexibility	Rigid	Rigid	Rigid	Rigid
Hardness Shore Durometer	D-94	D-95	D-88	D-89
SPECIFIC GRAVITY	2.2	2.3	1.55	1.55
YIELD STRENGTH psi Compressive, 0.2% offset	16,500	18,000	16,000	15,500
Elastic Modulus psi Compressive	1.1×10^6	1.3×10^6	0.8×10^6	0.7×10^6
Impact Strength (relative/Izod)	0.3	0.4	0.3	0.25
SERVICE TEMPERATURE °F (see Note 2.)	390°	390°	350°	350°
Thermal Conductivity BTU/hr-sq ft-°F/in	10.7	10.2	4.3	4.2
Thermal Expansion in/in per °F	14×10^{-6}	14×10^{-6}	22×10^{-6}	22×10^{-6}
Water Absorption % 24 hrs	0.15	0.15	0.1	0.1
Dielectric Strength volts/mil	380	380	450	450
Volume Resistivity ohm cm	10^{14}	10^{14}	10^{15}	10^{14}
Dielectric Constant • Dissipation Factor (tan δ) 60 c	6.5 • 0.02	6.5 • 0.02	4.8 • 0.02	4.6 • 0.02
1 kc	6.3 • 0.008	6.3 • 0.008	4.6 • 0.01	4.4 • 0.01
1 Mc	5.9 • 0.02	5.9 • 0.02	3.9 • 0.02	3.7 • 0.02
Relative Cost	Low	Low	Very low	Very low
Complete Data in	STYCAST® 2850-FT 7-2-7A	STYCAST® 2850-GT 7-2-7	STYCAST® 2651	STYCAST® 2651-MM

	Telephone	TWX
Canton, Mass.	(617) 828-3300	(617) 828-4848
Gardena, Calif.	(213) FAculty 1-6650	(213) 327-8416
Northbrook, Ill.	(312) 272-6700	(910) 686-0006

PLASTICS/CERAMICS FOR ELECTRONICS

Emerson & Cuming, Inc.

DIELECTRIC MATERIALS DIVISION
CANTON, MASSACHUSETTS

TECHNICAL BULLETIN 7-2-7A

STYCAST 2850FT

Versatile Epoxy Casting Resin with High Thermal Conductivity

Stycast 2850FT is a highly filled epoxy formulation with remarkably good over-all general properties. In addition to having excellent electrical grade insulation properties Stycast 2850FT has unusually high thermal conductivity and low thermal expansion. This combination of properties has shown Stycast 2850FT to be invaluable in solving problems where electrical insulation and mechanical protection must be maintained while coping with heat transfer considerations.

Stycast 2850FT is a highly versatile epoxy resin system which may be cured with any one of three curing agents. The choice of Catalyst should be made after reviewing your requirements with regard to the following guidelines.

CHOICE OF CURING AGENTS: From the information supplied below select the Catalyst which best suits your requirements.

CATALYST 24LV -- Room temperature curing -- 30 minutes pot life (1 lb. mass) -- lowest viscosity and best handling properties -- generally does not require vacuum deairing -- best thermal and mechanical shock -- not recommended for applications subjected to temperatures above 300°F -- will soften slightly above 250°F -- best adhesion.

CATALYST 9 -- Room temperature curing--45 minutes pot life (1 lb. mass)--highest viscosity but with modestly good handing properties--tough and rigid at all temperatures to 300°F.

CATALYST 11 -- Requires oven cure--4 hour pot life (10 lb. mass)--low viscosity with excellent handling properties --excellent thermal and mechanical shock--best electrical and physical properties at temperatures above 250°F-- can be used up to 400°F.

PROPERTIES (Approx.)

(Stycast 2850FT cured with Catalyst 11)

Viscosity at 25°C (catalyzed)	70,000 cps	Heat Distortion Point		347°F (175°C)
Thermal Conductivity, BTU/ft²/hr/°F/in.	10.7	Water Absorption (7 days)		less than 0.15%
Specific Gravity	2.2	Volume Resistivity (ohm-cm)	77°F	$5x10^{14}$
Tensile Strength	8,400 psi		302°F	$1x10^{12}$
Compressive Strength	16,500 psi	Dielectric Constant	1 kc	approx. 6.3
Flexural Strength	13,300 psi	Dissipation Factor	1 kc	below 0.01
Flexural Modulus	$2x10^8$ psi		1 Mc	below 0.02
Izod Impact (ft. lb./in. of notch)	0.3	Dielectric Strength (Volts/mil)		380
Thermal Expansion Coefficient per °C	$29x10^{-6}$	Machinability		Poor--must be ground

INSTRUCTIONS FOR USE:

General Instructions — Mix the entire contents of the shipping container to a uniform consistency each time before removing material. Power mixing is preferred. Mold Release 122S will prevent adhesion to molds. Where necessary entrapped air can be removed by vacuum deairing.

If Using Catalyst 24LV

1. Add and thoroughly blend 6 1/2 to 7 1/2 parts of Catalyst 24LV by weight for each 100 parts by weight of Stycast 2850FT. Slight warming (100°F) of the resin before catalyst addition will aid pouring and hasten bubble release.
2. Pour into mold. Allow to cure at room temperature (75°F) overnight or oven cure for 2 hours at 150°F.

If Using Catalyst 9

1. Add and thoroughly blend 3 to 4 parts Catalyst 9 by weight for each 100 parts by weight of Stycast 2850FT. Slight warming (100°F) of the resin prior to adding catalyst will improve pourability. Small amounts (up to 10% by weight) of Eccobond 55 (See Technical Bulletin 3-2-1) may be added to further lower viscosity with some sacrifice in properties.
2. Pour into mold. Allow to cure at room temperature (75°F) overnight or oven cure for 2 hours at 150°F.

If Using Catalyst 11

1. Add and thoroughly blend 4 to 5 parts by weight of Catalyst 11 for each 100 parts by weight of Stycast 2850FT. Stycast 2850FT may be heated at any temperature up to 165°F before catalyst addition to lower viscosity and aid pourability.
2. Pour into mold. Cure at any of the following schedules: 165°F for 16 hours or 212°F for 3 hours or 257°F for 1 hour.

For optimum high temperature performance post cure for 4 hours at 300°F.

Telephone / TWX
Canton, Mass. (617) 828-3300 (617) 828-4848
Gardena, Calif. (213) FAculty 1-6650 (213) 327-8415

PLASTICS/CERAMICS FOR ELECTRONICS

Emerson & Cuming, Inc.

DIELECTRIC MATERIALS DIVISION
CANTON, MASSACHUSETTS

TECHNICAL BULLETIN 7-2-10A
STYCAST 2651MM

Low Viscosity General Purpose Epoxy

Stycast 2651MM is a low viscosity general purpose casting resin. It can also be used effectively as an impregnant in certain applications. When fully cured, Stycast 2651MM has approximately the same physical and electrical properties as Stycast 2651. It has been introduced to cover those applications where improved flowability is required. Instructions for catalyst addition, handling and cure schedules are identical with those of Stycast 2651.

Stycast 2651MM is used in a variety of electronic and electrical encapsulation applications. Color is normally black, but color coding is possible. By incorporation of Filler SC, it can be used as a dip coat for components.

As an indication of the low viscosity obtainable with the Stycast 2651MM-Catalyst 11 system, data is presented below. Resin and catalyst were heated to the indicated temperature and mixed (100 Parts by Weight Stycast 2651MM and 8 Parts Catalyst 11), the viscosity was taken immediately. **Pot life is, of course, shortened by increased temperature, but in production operations using a dispenser, this is not a problem.**

Temperature (100 parts Stycast 2651MM 8 parts Catalyst 11)	Viscosity Brookfield Centipoises	Approx. Pot Life at Temperature
75°F	4500	4 hours
100°F	2800	3½ hours
125°F	1500	3 hours
150°F	800	2½ hours
170°F	600	2 hours
200°F	400	¾ hour
225°F	150	½ hour
250°F	below 100	¼ hour

Stycast 2651MM can, of course, be used with Catalyst 9 (see room temperature cure below). A decrease in viscosity is obtainable with increased temperature. In this case, **pot life is so limited that automatic dispensing equipment is a necessity.**

Properties of Stycast 2651MM cured with Catalyst 11 **are as follows:**

Tensile Strength, psi	7000
Compressive Strength, psi	14,000
Flexural Strength, psi	12,000
Izod Impact (ft. lb/in. of notch)	0.2
Thermal Expansion Coefficient per °C	25×10^{-6}
Water Absorption (7 days at 25°C)	0.15%
Volume Resistivity (ohm-cm) 25°C	4×10^{16}
150°C	7×10^{12}
Dielectric Constant, to 10^{10} cps	4.2
Dissipation Factor, to 10^{8} cps	0.01
to 10^{10} cps	below 0.02
Dielectric Strength (Volts/mil-100 mil sample)	440
Machinability	Excellent

INSTRUCTIONS FOR CURING

Elevated temperature cure—Cure with Catalyst 11 will produce the ultimate in strength properties at high temperature.

1. Mix the resin in the shipping container until it is uniform in texture. This will normally require 2-5 minutes in 1 or 5 gallon containers.
2. Use 8% Catalyst 11 by weight on the basis of the amount of Stycast 2651MM required. Mix thoroughly. The catalyzed resin has at least 4 hours pot life.
3. Pour. Use vacuum evacuation only if required. Normally, this will not be the case. Mold Release 122S is usually adequate.
4. Cure for 2 hours at 210-220°F for castings below 200 grams. Otherwise, cure for 8 hours at 160-170°F. Castings may be gelled in 24 hours at room temperature and should be cured for one hour at 210°F.

ROOM TEMPERATURE CURE

1. Mix the resin in the shipping container until it is uniform in texture. This will normally require 2-5 minutes in 1 or 5 gallon containers.
2. Add 6-7% by weight Catalyst 9 and stir thoroughly. Pot life is about ½ hour. Keep Catalyst 9 away from contact with the skin.
3. Pour. Use vacuum evacuation only if necessary.
4. Allow to stand at room temperature for 8 hours. (Catalyst 11 can be used for room temperature cure. See above.) The casting can be removed from the mold when hard. This will occur within 1 hour.
5. **A one hour cure at 160-170°F immediately after pouring will also complete the cure with Catalyst 9.**

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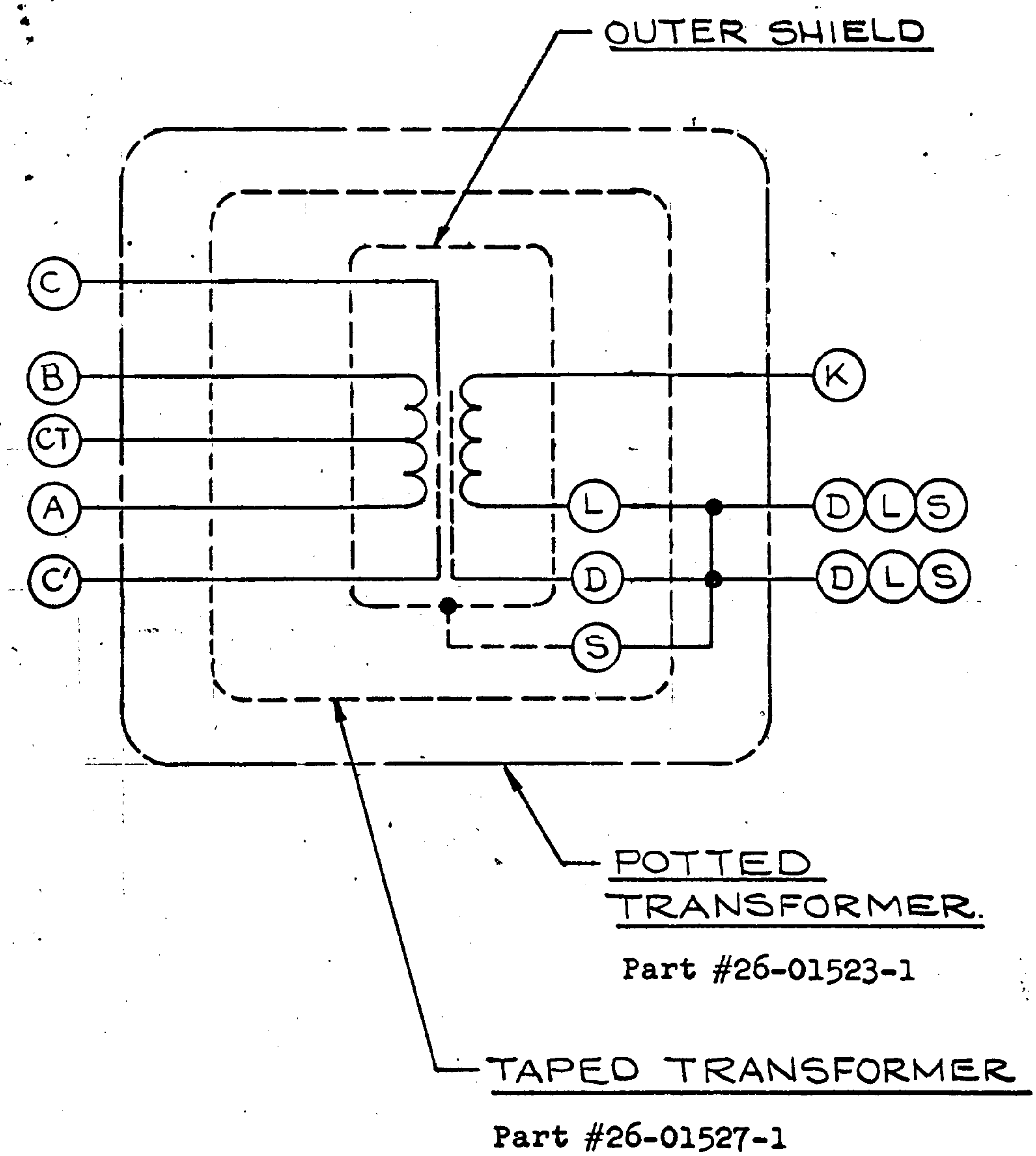
2.1.3.1 Pickoff Transformer Specifications

Included in report #8 covering March 1967, was a section on Bridge Transformer testing. A sample set of transformer specifications have been drawn up to cover the before and after potting characteristics of the transformer. They are as follows:

TABLE II

	SPEC. PARAMETER	BEFORE POTTING	AFTER POTTING
1.	Primary Inductance	11 - 13 mh	11 - 13 mh
2.	Q at 180 KC (Pri)	>12.0	>10.0
3.	Primary Distributed Capacity	<30.0 pf	<35.0 pf
	(a) With primary shield to Lead A	<30.0 pf	<35.0
	(b) With primary shield to Lead B	<30.0 pf	<35.0
4.	Secondary Inductance	2.5 - 3.5 mh	2.5 - 3.5 mh
5.	Secondary Distributed Capacitance	<75.0 pf	<80.0 pf
6.	Q at 180 KC (Sec)	>12.0	>10.0
NOTE:	Capacitance difference between 3a and 3b must be less than 3.0 pf.	<3.0 pf	<3.0 pf



BRIDGE PICKOFF TRANSFORMER SCHEMATIC

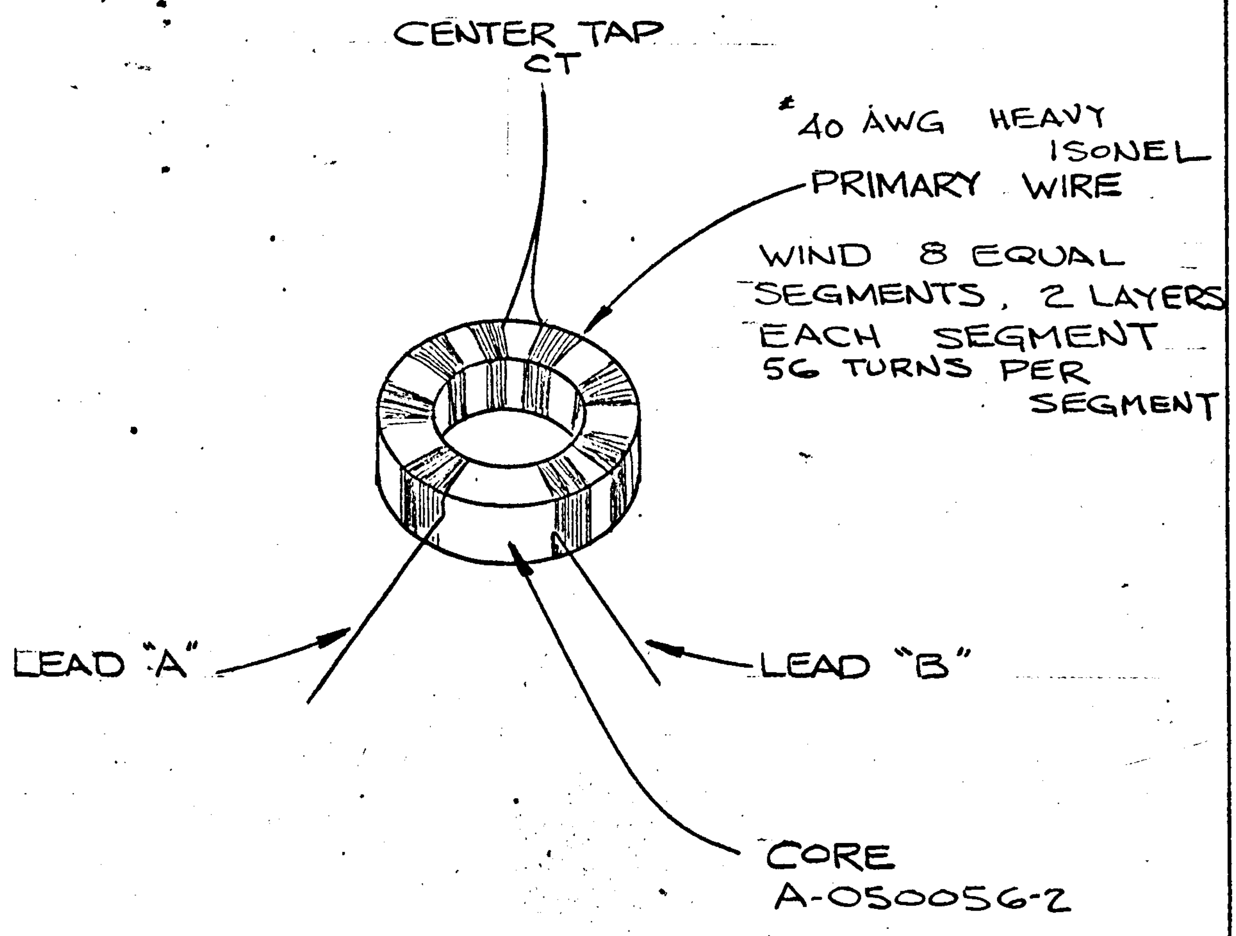
FIGURE 2E

TABLE III

192 KC TRANSFORMER (CONSTITUANT PARTS)

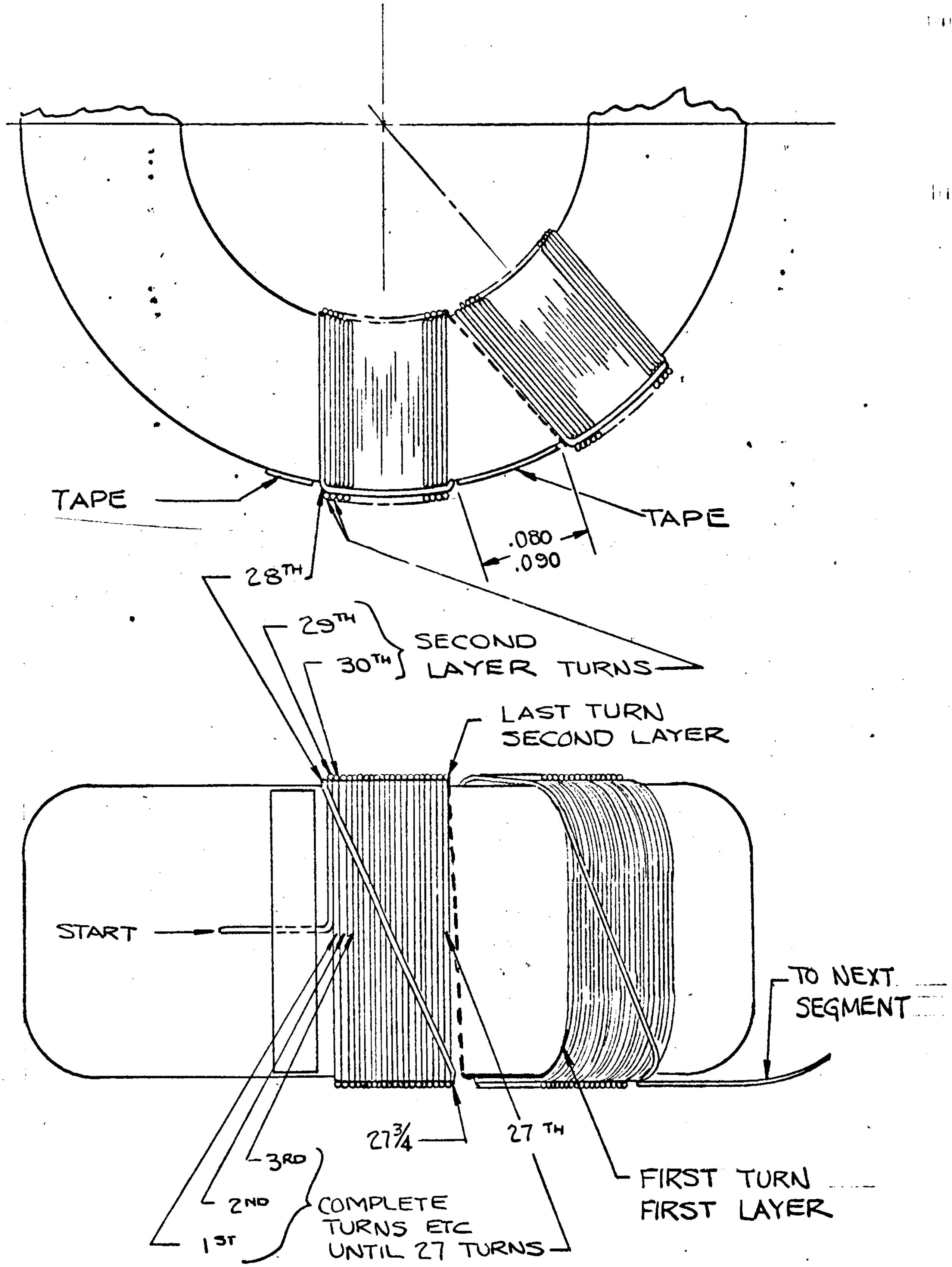
		MANUFACTURER	MANUFACTURING PART NUMBER	DESCRIPTION	MAXIMUM OPERATING TEMPERATURE	NOTES
a)	Core	Arnold Eng.	A-050056-2	Molybdenum Permalloy Powder Core	$350^{\circ}F$	Core would stand higher temps - Enamel encapsulant won't
b)	Magnet Wire	Hudson Wire	40-H12	#40 AWG Wire	$185^{\circ}C$	Used on primary and secondary heavy isonel 200
c)	Insulating Tape	Mystic	#7020	Pressure sensitive glass cloth tape		Appears on JPL approved material list
d)	Shields	Bell	C6-4107-009-1 C6-4107-011-1 C6-4107-012-1	Brass Alloy Cambridge ASTM -B-36 ½ hd., .0015 thick	$350^{\circ}F$	Drawn Shields soldered with 60/40 solder in final XFMR
e)	Potting Compound	Emerson & Cumming	Stycast 2850' Catalyst 11	Hi Thermal Conductivity Casting Resin	$400^{\circ}F$	Appears on JPL approved potting & encapsulant list

It is felt with the above components the transformer will meet the circuit requirement as well as the sterilization environments.



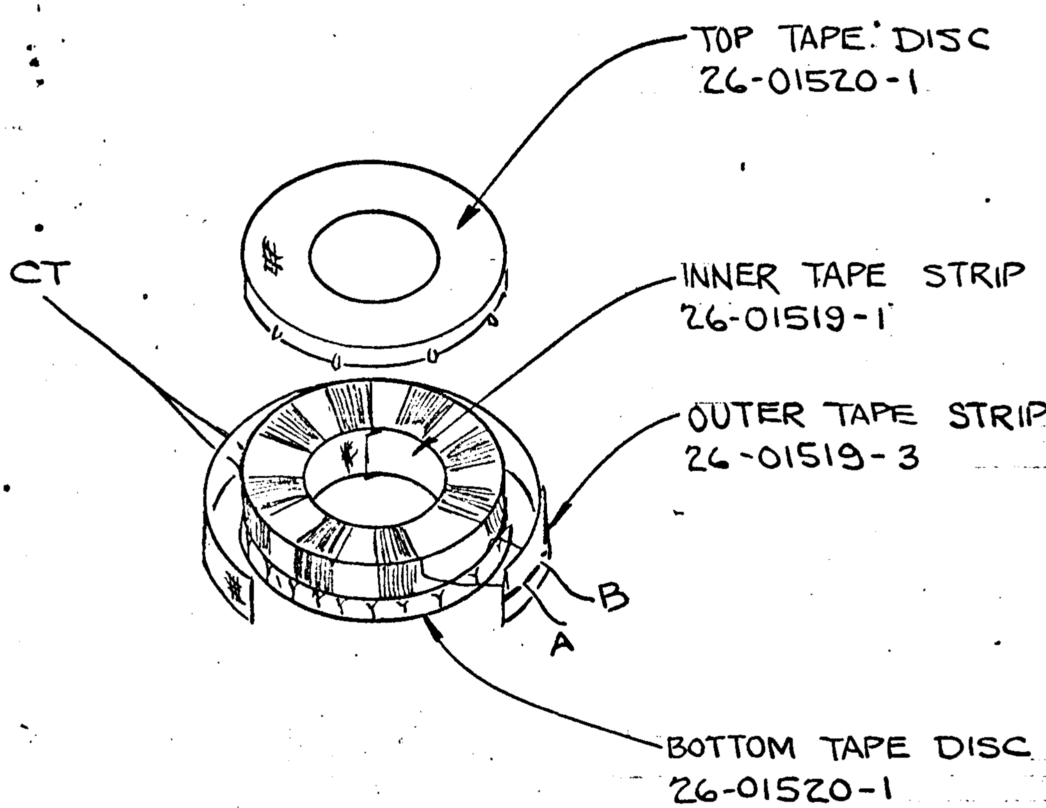
PRIMARY WINDING

FIGURE 3E



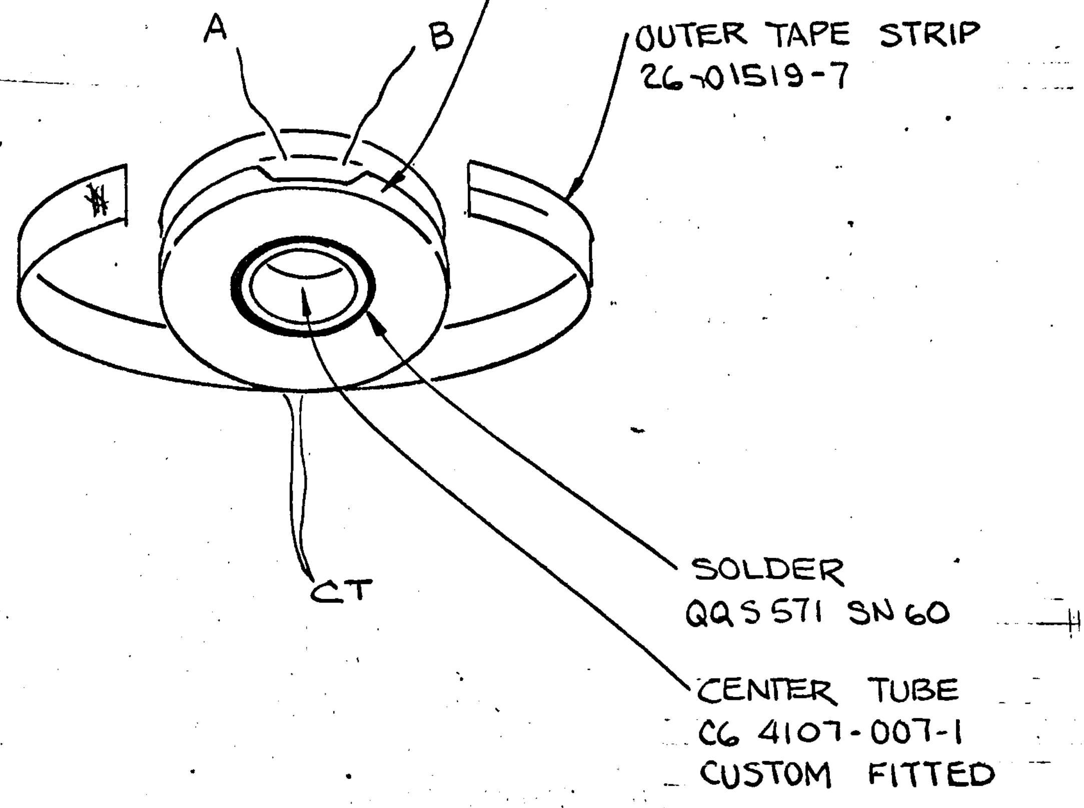
PRIMARY SEGMENT WIND

FIGURE 4E



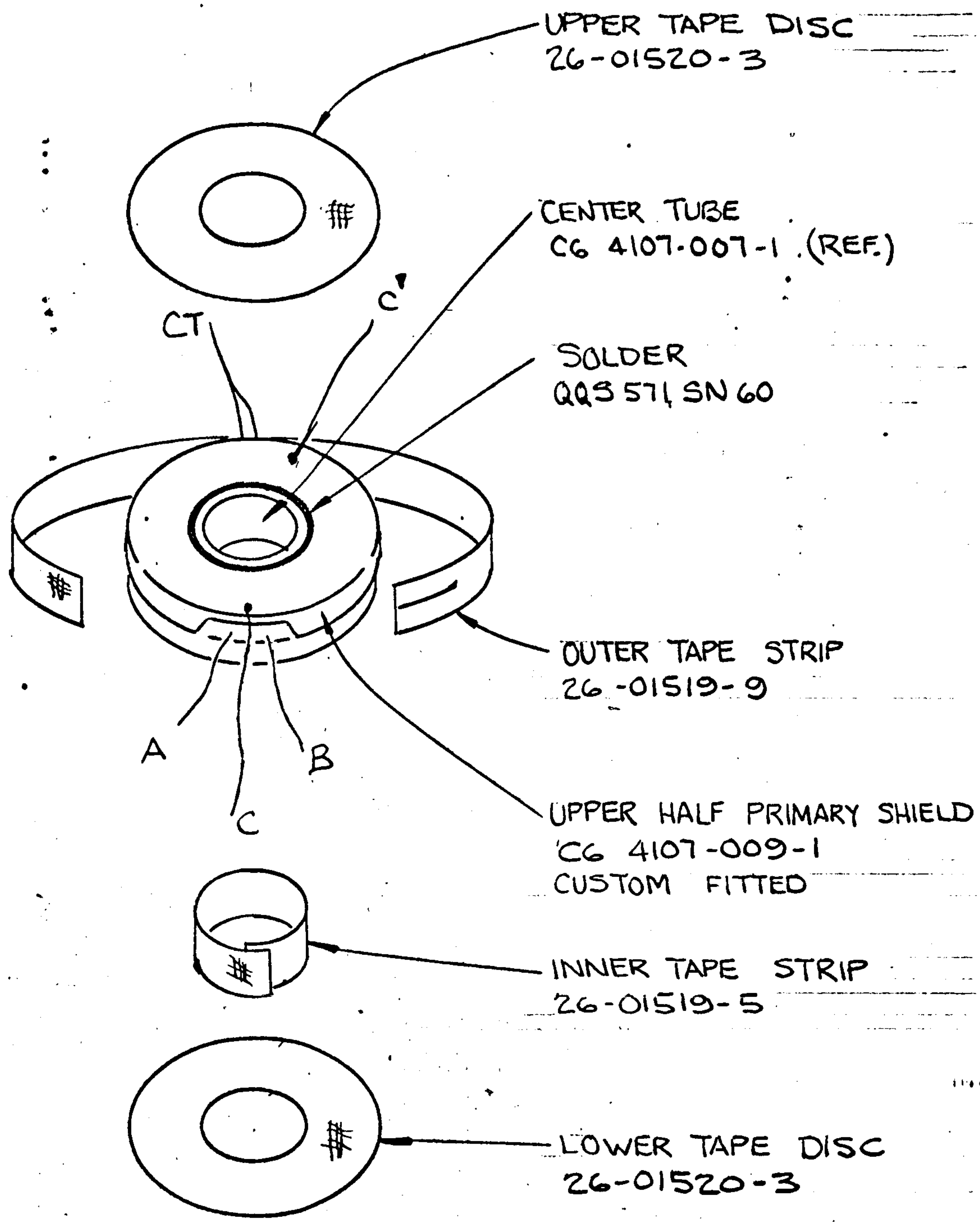
TAPED PRIMARY

FIGURE 5E



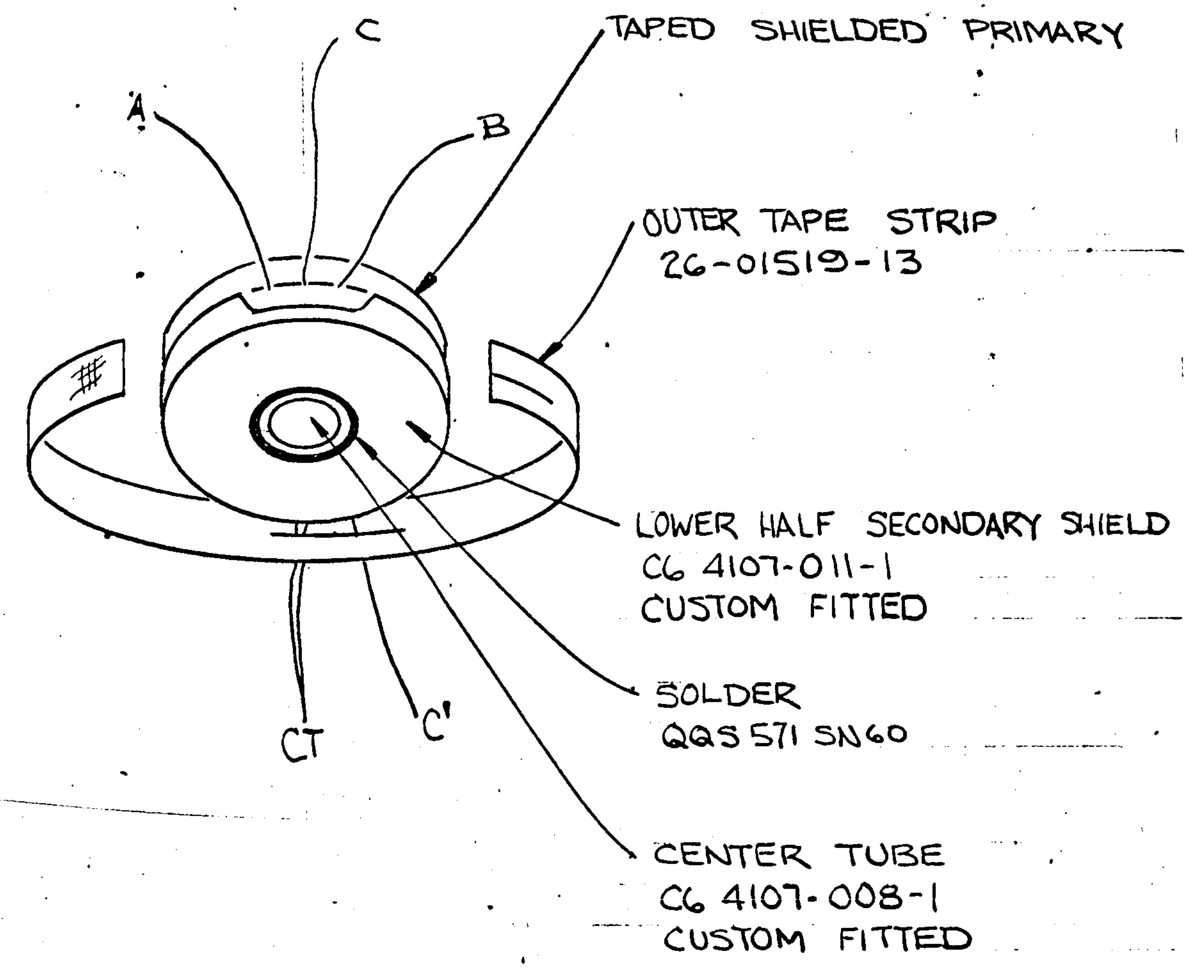
TAPED PRIMARY &
½ PRIMARY SHIELD

FIGURE 6E



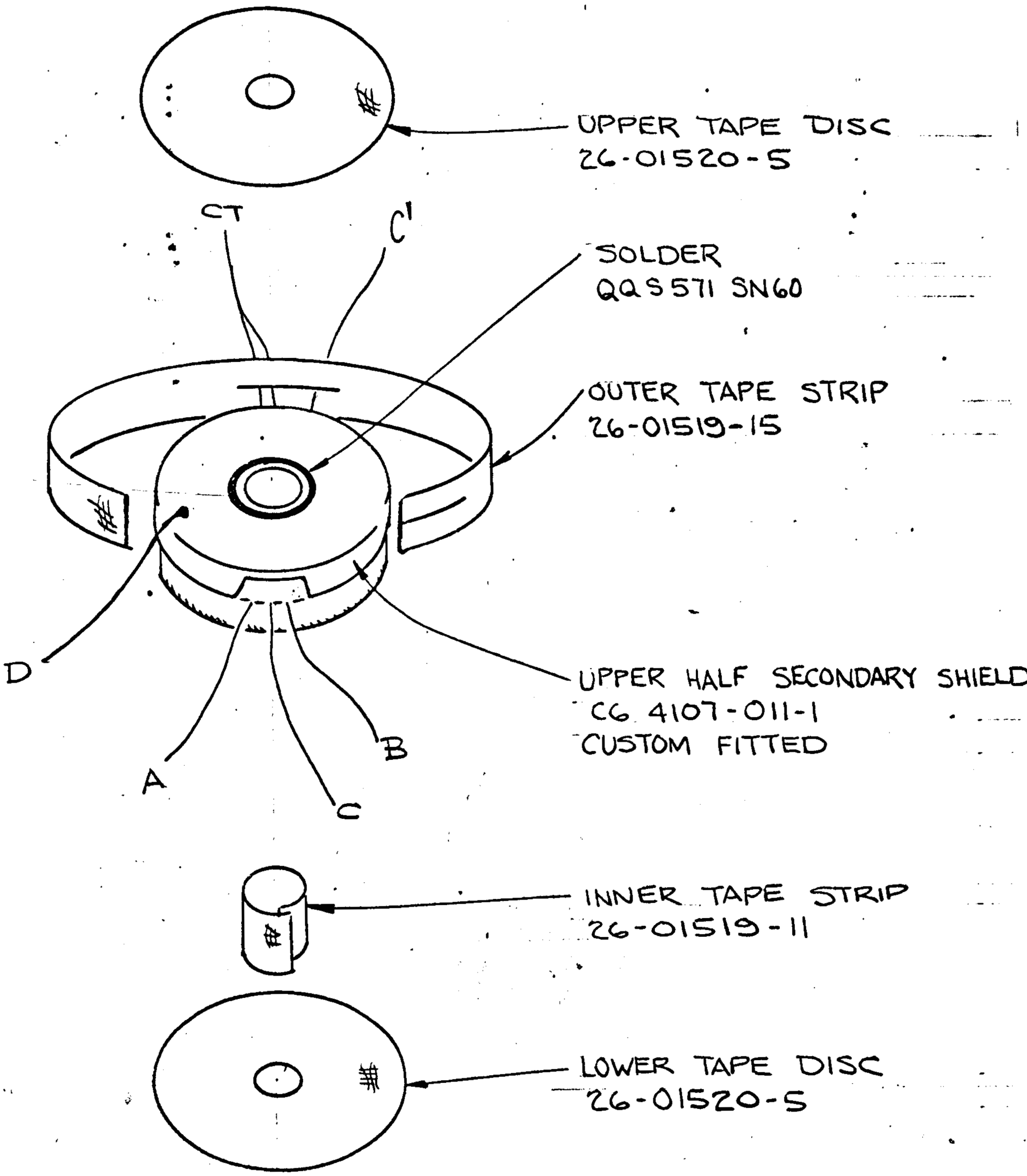
TAPED PRIMARY &
PRIMARY SHIELD

FIGURE 7E



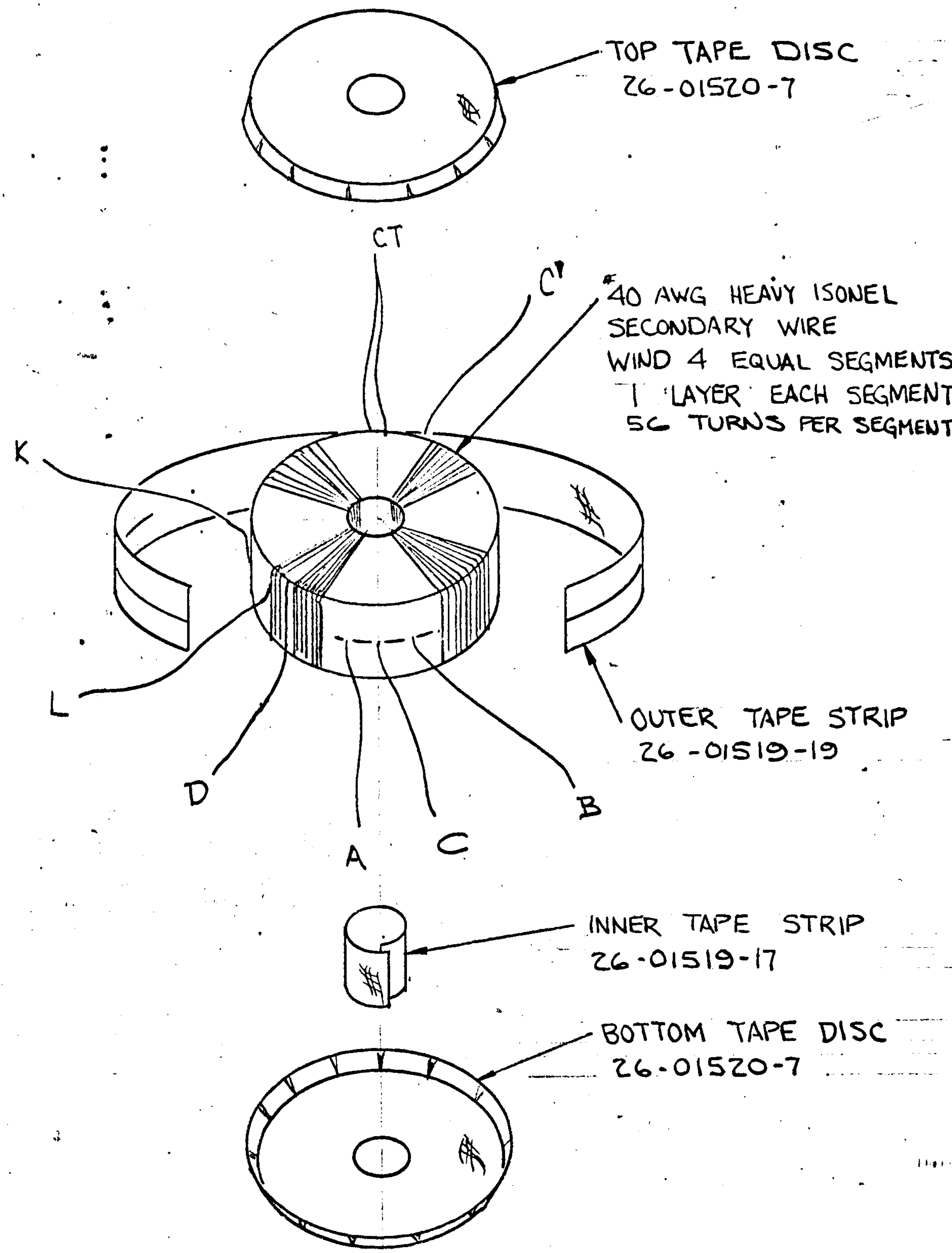
TAPED PRIMARY SHIELD &
1/2 TAPED SECONDARY SHIELD

FIGURE 8E



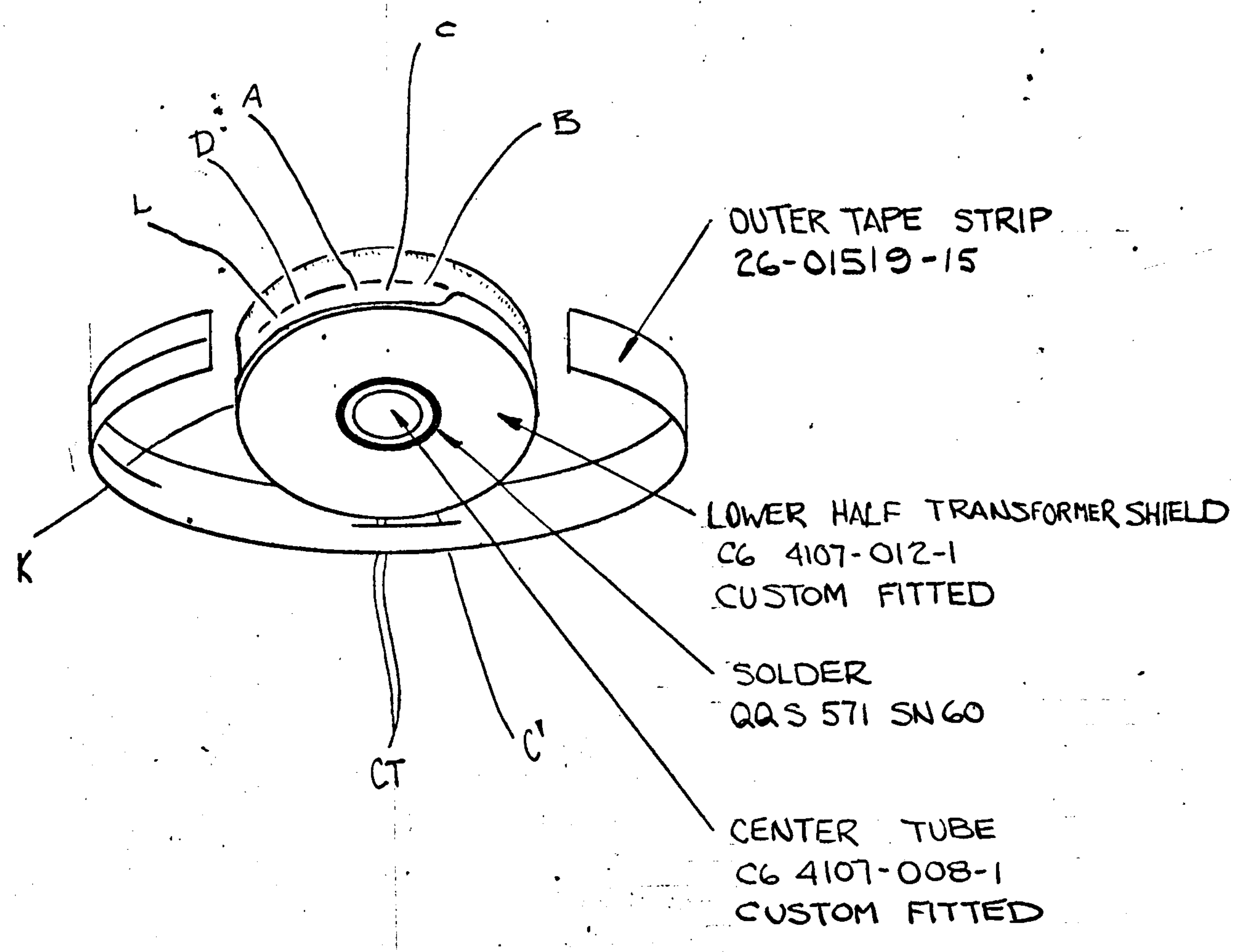
TAPED PRIMARY & SECONDARY SHIELD

FIGURE 9E



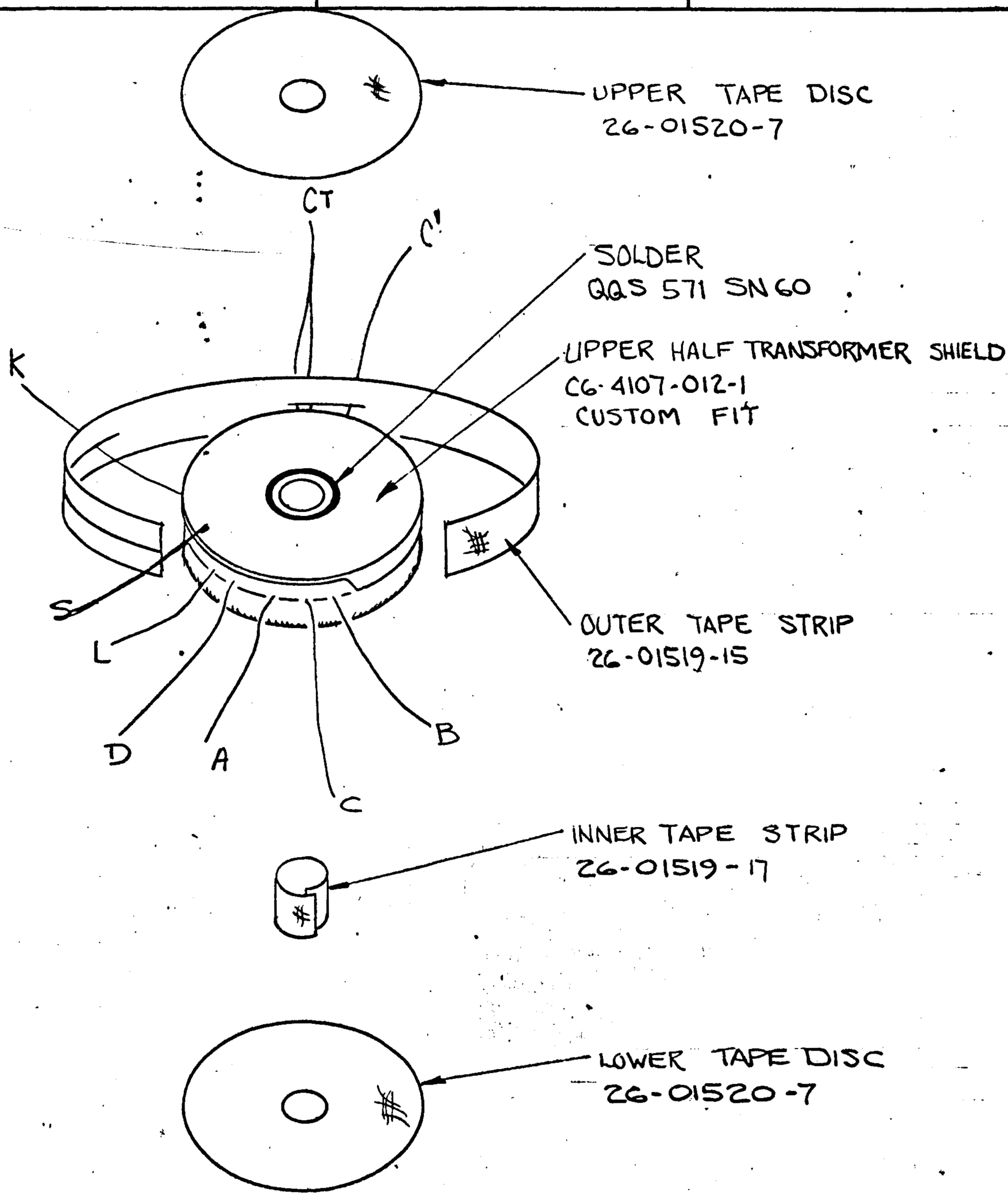
SECONDARY WINDING

FIGURE 10E



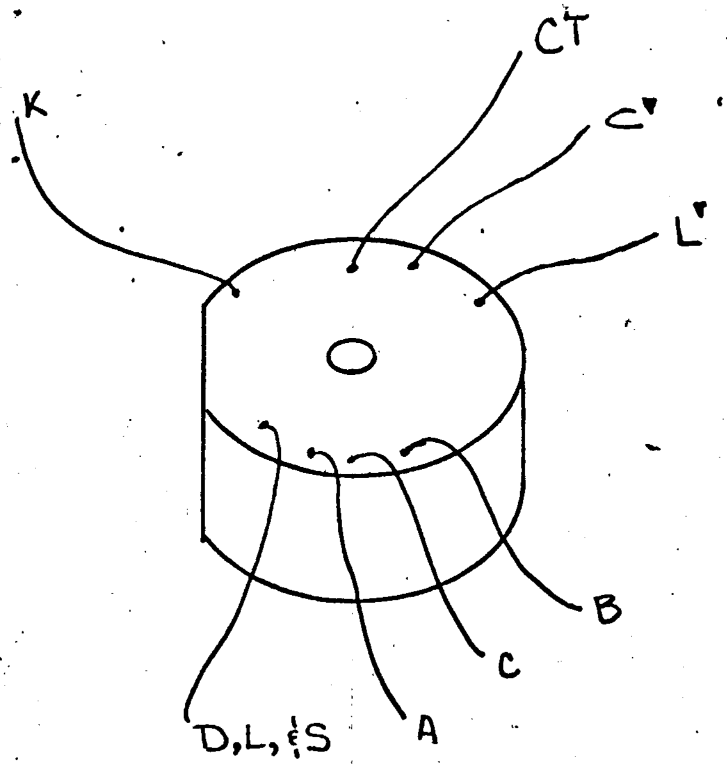
TAPED & SHIELDED PRIMARY & SECONDARY AND 1/2 TAPED TRANSFORMER SHIELD

FIGURE 11E



SHIELDED & TAPED TRANSFORMER

FIGURE 12E



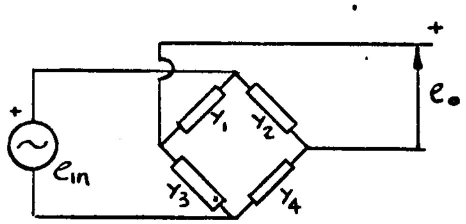
COMPLETE PICKOFF
TRANSFORMER

FIGURE 13E

2.1.4 Pre-Amplifier Bridge Characteristics (Bonnet Characteristics)

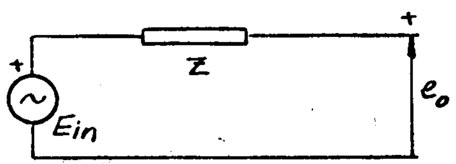
Any bridge circuit, with a voltage source at its input terminals and the output terminals open circuited, can be represented by a Thevenin's voltage source and a series impedance or Norton's current generator and a shunt impedance.

If the admittances of the bridge y_1, y_2, y_3, and y_4 are as the figure indicates, the Thevenin's voltage source equals:



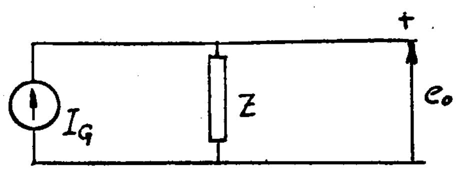
$$e_o = E_{in} = \frac{Y_2 Y_3 - Y_1 Y_4}{(Y_1 + Y_3)(Y_2 + Y_4)} \quad (1)$$

The series impedance:



$$Z = \frac{Y_1 + Y_2 + Y_3 + Y_4}{(Y_1 + Y_3)(Y_2 + Y_4)} \quad (2)$$

The equivalent current generator



$$I_G = \frac{Y_2 Y_3 - Y_1 Y_4}{Y_1 + Y_2 + Y_3 + Y_4} e_i \quad (3)$$

In determining the equivalent circuit for the pendulum bridge the following assumptions have been made:

(a) The deflection angles are small compared to the 6 mils spacing, thus, surfaces of the pendulum capacitors are regarded as being always parallel.

(b) The stray capacitances between the pendulum and the case, also fringing capacity are independent of the deflection angle.

(c) The sum of fixed bridge capacitor and stray capacitances is 15 mmf. This assumption will be checked by lab. experiment.

The current generator equals:

$$I_G = j\omega_r C_n C e_i \frac{\varepsilon}{(C+C_o)(1-\varepsilon^2)+C_n} \qquad (4)$$

ω_r = Resonant angular frequency

C_n = Pendulum capacitance at zero deflection

C = Fixed bridge capacitor

C_o = Stray capacitance between pendulum and ground

ε = Ratio of pendulum deflection to total spacing

The shunt impedance equals:

$$Z = \frac{2}{j\omega} \cdot \frac{(C+C_o)(1-\varepsilon^2)+C_n}{(C+C_o+C_n)^2-(C+C_o)^2\varepsilon^2} \qquad (5)$$

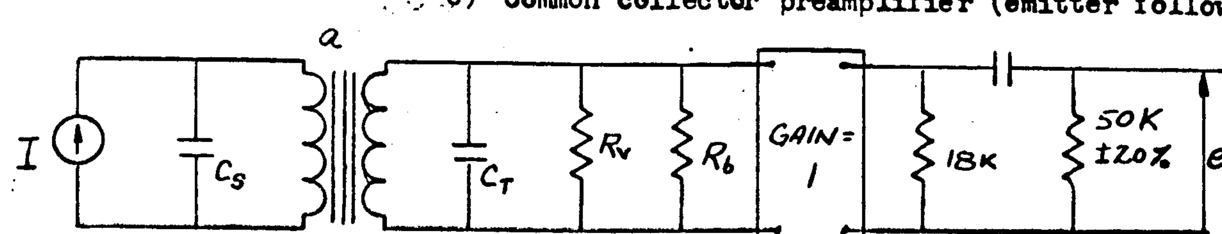
2.1.5 <u>System's Equation</u>

2.4.1 The system consists of:

a) Norton's equivalent of the bridge circuit

b) Equivalent circuit of the transformer

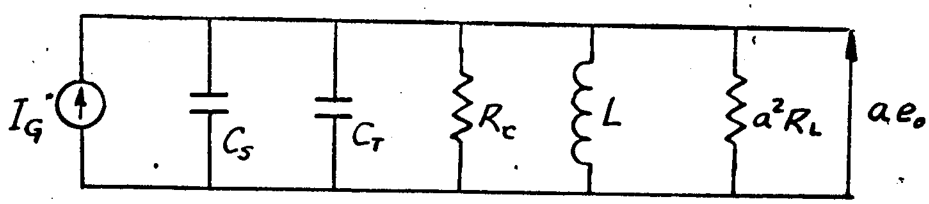
c) Common collector preamplifier (emitter follower)



Due to the transistor gain tolerance and the lead tolerance, the input impedance Z_o of the preamplifier is within the range

$$Zo = \frac{QeWrL}{a^2B}$$

The equivalent circuit of the system:



C_S = Capacitor of the current source

C_T = Sum of secondary side stray and tuning capacitors reflected to the primary side and stray capacitance of the primary side.

R_c = Equivalent resistance of core losses

L = Transformer primary inductance

R_L = Lead resistance equal to parallel combination of Z_{in}, bias resistance R_b = 330k and R_v

a = Turns ratio of the transformer

For the tuned circuit, the system gain equals:

$$A = \frac{e_o}{e_i} = \frac{\omega_r^2 C_n C L Q_T}{a} \cdot \frac{\mathcal{E}}{(C+C_o)(1-\mathcal{E}^2)+C_n}$$

The terms appearing here have been defined on previous pages.

In the vicinity of zero pendulum deflection where

$$\mathcal{E}^2 << 1 \qquad (6)$$

the gain expression can be simplified to the following term:

$$A = \frac{\omega_r^2 C_n C L Q_T}{a(C + C_o + C_n)} \mathcal{E} \tag{6a}$$

The output impedance of the system at resonance equals the total resonant impedance of the transformer reflected to the secondary side of the transformer. Viewed from the output terminals of the emitter follower, the impedance becomes:

$$Z_o = \frac{R_T}{a^2}\left(\frac{1}{\beta}\right) = \frac{\omega_r L Q_T}{a^2 \beta} \tag{7}$$

R_T = Parallel combination of R_c and $a^2 R_L$

2.1.6 Electrical Torquing Scheme (Null Bias)

Normally some provision must be made to electrically correct the accelerometer unbalance caused by small unbalance conditions in the sensitive bridge circuit. This can be readily accomplished in more than one way. One method is by making a capacitance correction in the sensitive bridge circuit. However, this becomes very impractical because any adjustment in the critical bridge circuit also introduces stray capacitances whose performance is extremely difficult to predict. A second method which can be used is when the pickoff transformer is tuned to resonance. When operating at resonance, the output voltage at the secondary of the transformer is shifted 90° from the bridge excitation signal. This allows a signal to be fed via a capacitor, which also is shifted by 90° from the bridge excitation signal, into the secondary. (See Figure 14E) This is a more desirable way of electrically torquing.

The design, as it exists today, does not specifically define the electrical torquing scheme. It allows for either a single variable capacitor from bridge excitation high to the high side of the secondary of the pick-off transformer, a variable capacitor across either of the fixed bridge capacitors or a variable differential capacitor across both fixed capacitors minus torques without any unbalance in the bridge circuit. With the single ended variable capacitor, a fixed unbalance must be placed in the bridge circuit in order to correct both plus and minus torques.

Figure 15E illustrates the single ended variable capacitor design and can be explained in the following manner:

Condition:

1) Assume voltage out of the preamplifier due to torquing capacitor is as indicated $V_{TC} \angle 90°$.

2) Assume at pendulum equilibrium the voltage (error signal) out of the bridge circuit is $V_B \angle -90°$ and has the same magnitude as $V_{TC} \angle +90°$. The resultant voltage at the

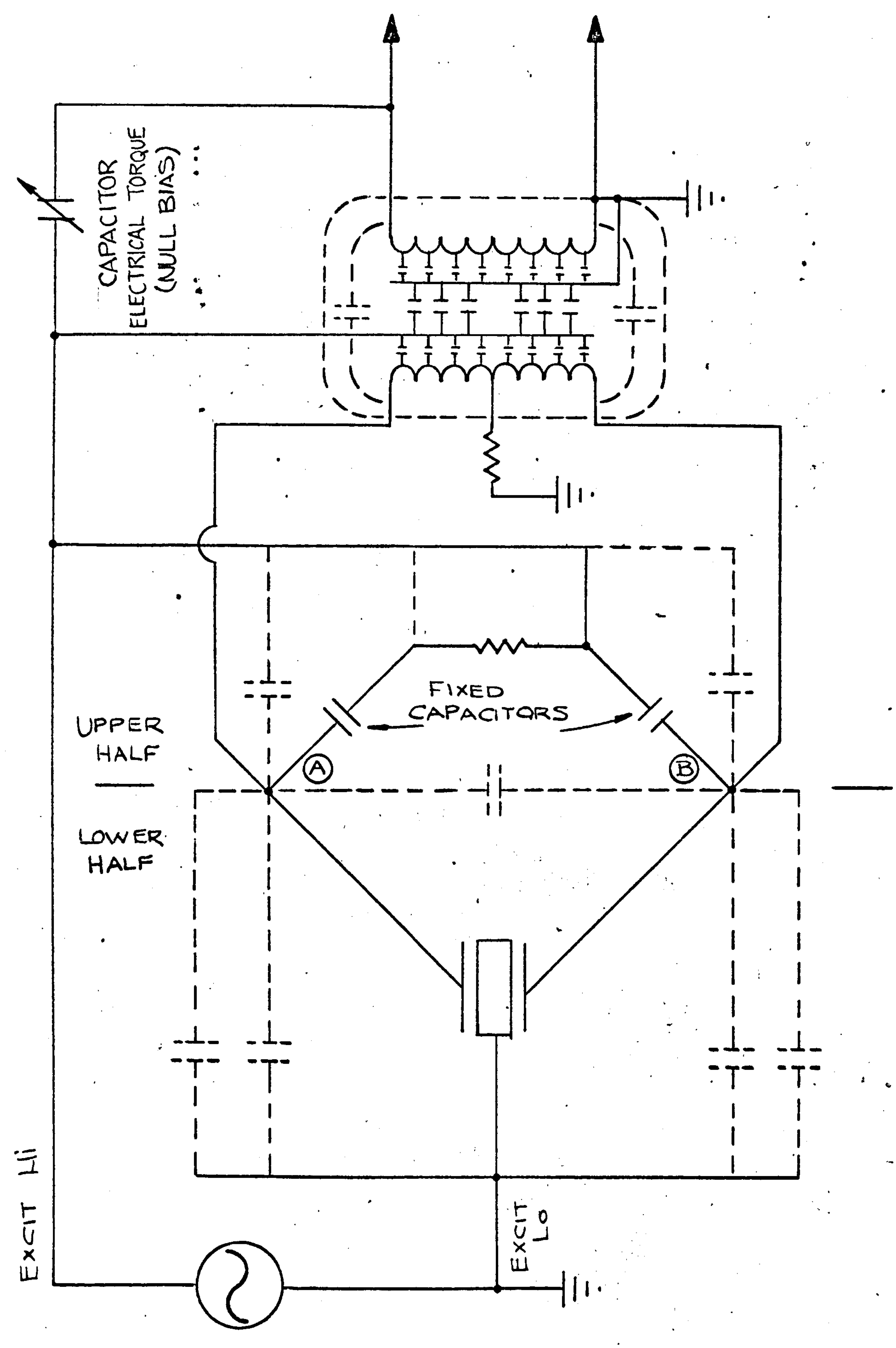
bonnet output therefore is $V_{TC} \angle +90° + V_B \angle -90°$ or zero volts.

Assume at pendulum equilibrium the bonnet output is zero (NOTE: at pendulum equilibrium the bottom half capacities in the capacitance bridge are equal).

Assume the pendulum swings in a $+\phi$ direction. This in turn causes $V_P (+\phi)$ to increase in magnitude, or for purpose of discussion, say it goes in the same direction as the original cancelling V_B. Now the output as seen at the bonnet output is $V_{TC} \angle +90° + V_B \angle -90° + V_P (+\phi) \angle -90° = V_{TC} = (V_B + V_P (+\phi)) \angle -90°$. The net result is an output voltage which is directly proportional to $V_P (+\phi)$.

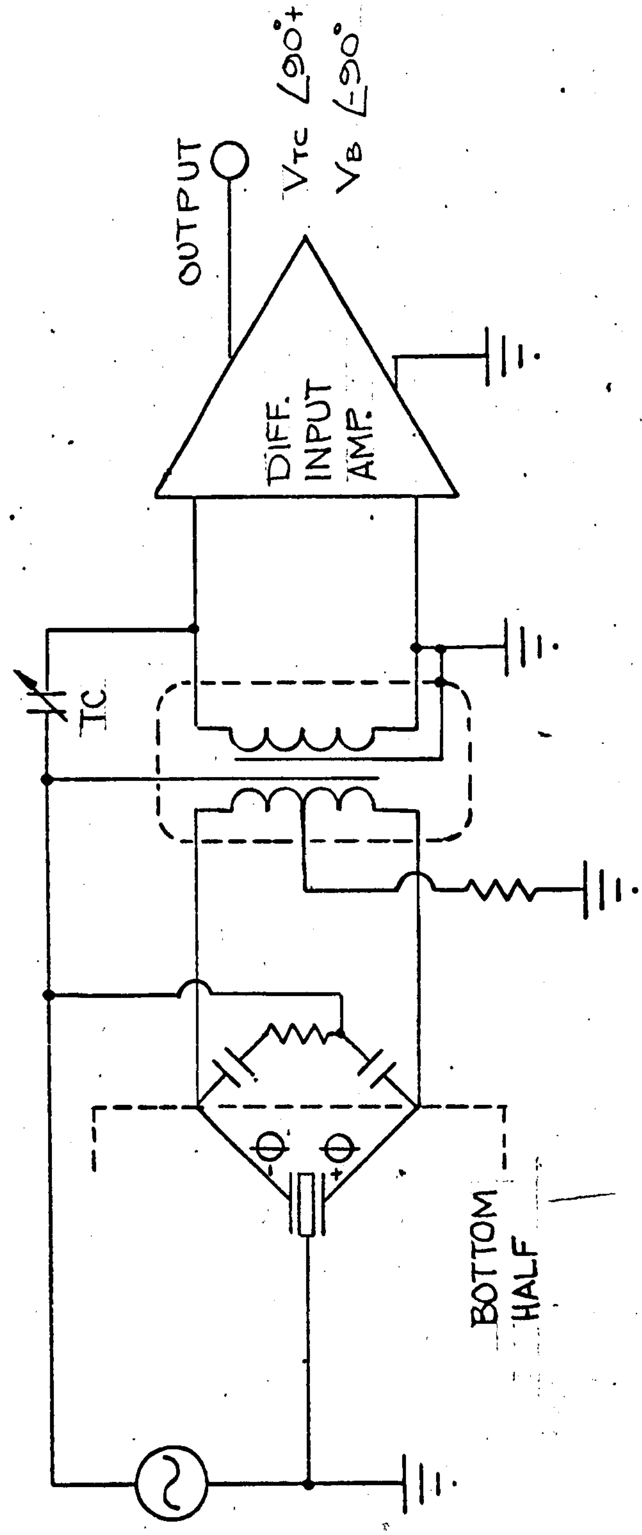
Thus, it can be seen that electrically torquing can be accomplished satisfactorily by the single ended method. The drawback, of course, is that the upper half of the bridge must be unbalanced so that an error signal is obtained which is equal and opposite in magnitude and phase to that produced by the torquing capacitor. This is necessary in order to obtain zero output out of the accelerometer when the pendulum is in its equilibrium position. This is easily accomplished, however, by selecting fixed bridge capacitors in the upper half of the bridge which are of different value.

Both approaches were evaluated in the engineering design and the single ended variable capacitor feeding the high side of the pickoff transformer secondary was agreed upon.



BALANCED BRIDGE CIRCUIT WITH ELECTRICAL BIAS

FIGURE 14E



ELECTRICAL TORQUING SCHEME

(NULL BIAS)

FIGURE 15E

2.1.7 Parameter Adjustments

2.1.7.1 Gain (Band Width)

The gain of the preamplifier will be adjusted while on the accelerometer to obtain a pickoff sensitivity of 40 milli-volts ±5 milli-volts/milli-radian. This adjustment is made by selecting a fixed value resistor which shunts the secondary of the bridge pickoff transformer, R_Z on Figure 16E.

2.1.7.2 Phase Angle

The phase of the output signal is adjusted while the bonnet is on an accelerometer simulator. The signal at the output of the preamplifier must be $90^{\circ} \pm 10^{\circ}$ out of phase with the bridge excitation signal. This adjustment is made via the selection of a fixed capacitor which is physically located across the secondary of the pickoff transformer, C_3 Figure 16E.

2.1.7.3 Quadrature

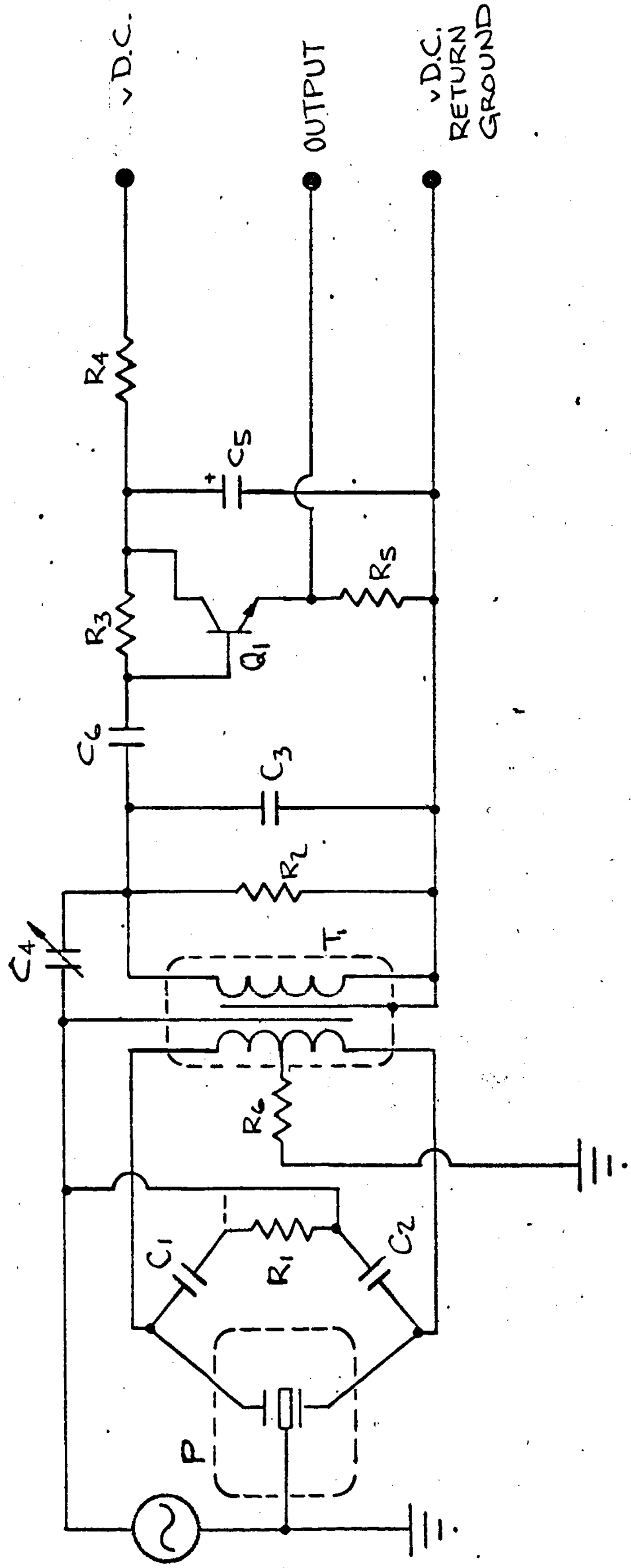
The quadrature component of the output signal is adjusted while the bonnet is on an accelerometer simulator. This is done by selecting a fixed resistor in the bridge circuit, R_1, on Figure 16E. After this adjustment is made, it is rechecked along with the phase angle on an accelerometer. It may be necessary to reselect a new resistor value while on the accelerometer in order to minimize quadrature.

2.1.7.4 Output Impedance

The output impedance need not be adjusted unless the Beta of the output transistor falls below specification. Should the output impedance for some reason be too high, the output transistor could be replaced. However, this should not be necessary in that the design allows for the minimum Beta spread on the 2N930 transistor, such that the output impedance will always be less than 500 ohms, Q on Figure 16E.

2.1.7.5 Input Impedance

This is basically a fixed parameter. It is dependent on the capacity which exists between primary and secondary shields of the pickoff transformer. This is checked while the transformer is external of the bonnet assembly. The input impedance will be 9.0 K ohms or greater.



SCHEMATIC DIAGRAM

FIGURE 16E

2.1.8 Packaging

The packaging of the bonnet is patterned around the conventional cord wood construction. The design consists of the mechanical and electrical parts listed in Table IV and Table V. Figures 17E and 18E illustrate the circuit board design. Figure 19E shows a typical bonnet construction.

The circuit boards are of plated through hole construction, and redundancy is used wherever possible on the circuitry layout. This is, circuitry is carried on both sides of the board, except in areas where it was necessary to cross circuit patterns.

The volume in which the bonnet must fit is limited. This type of construction was decided upon because it provides high density packaging. This basic construction and packaging concept has been utilized successfully by Bell Aerosystems Company in many other accelerometer designs.

The packaging technique meets the specification as written in MSFC STD 154, amended April 29, 1964.

TABLE IV

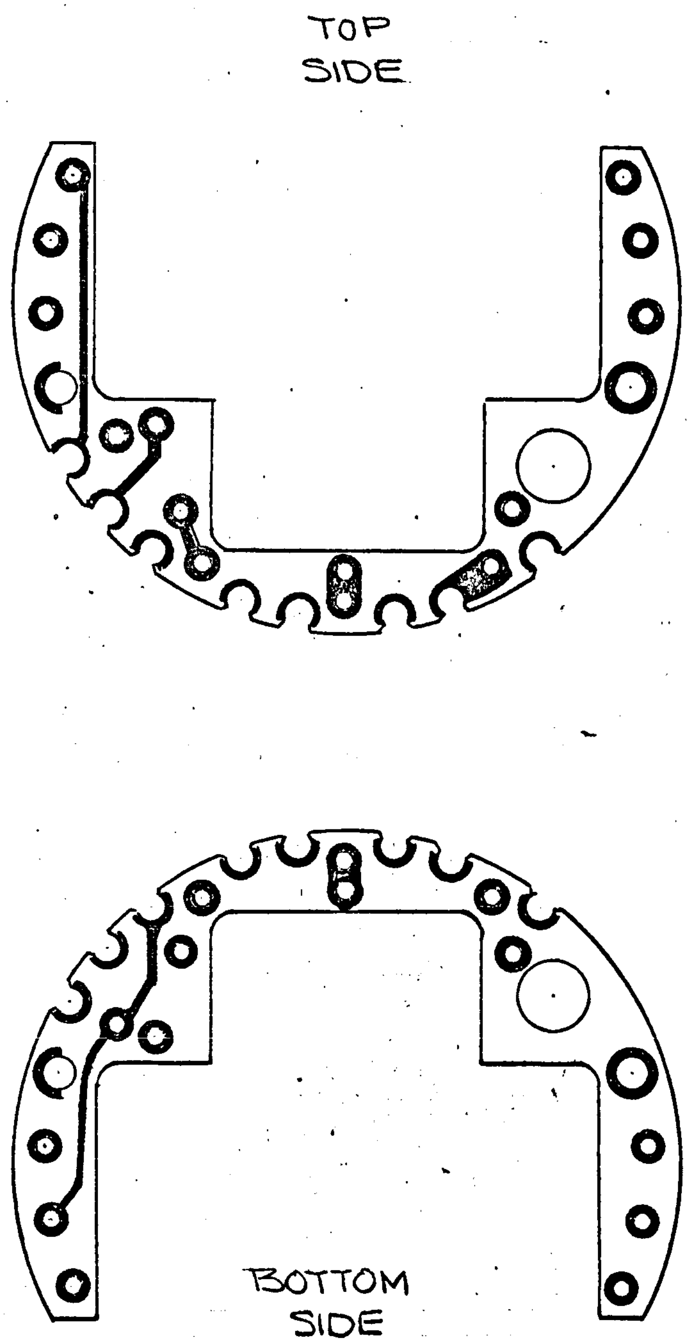
MECHANICAL PARTS

	NAME	PART NUMBER
1.	Cover Top Assembly	26-00995-1
2.	Hex. Soc. Set Screw	#1-72 x .312
3.	Washer Insulator	26-01027-3
4.	Upper Board	26-00565-3
5.	Washer Insulator	26-01027-1
6.	Bracket	26-00597-1
7.	Washer	26-00754-1
8.	Hex Nut	#1-72 J.I. Morris
9.	Screw	26-00755-1
10.	Washer	26-00754-1
11.	Washer	26-01028-3
12.	Lower Board	26-00568-3
13.	Washer	26-01023-AR

Form 0345 Rev. 1248

TABLE V JPL ACCELEROMETER ELECTRONIC COMPONENTS

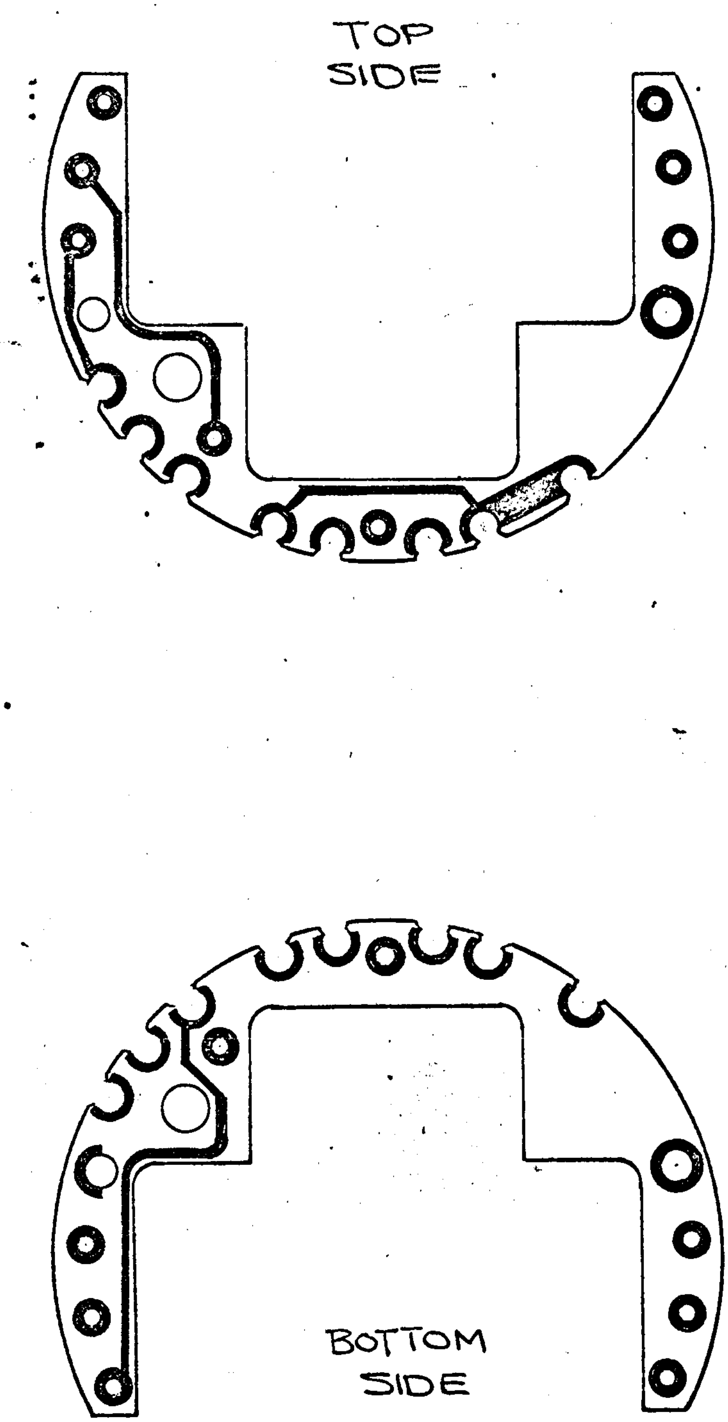
	Component	Function	Value	Rating	Component Type & Manufacture
C_1	Capacitor	Bridge Arm	15 pf ±5%	500 V	CYFR Corning — Per Corning Spec. J951 Inspection Level B dated
C_2	Capacitor	Bridge Arm	≅ 15 pf ±5%	500 V	CYFR Corning
C_3	Capacitor	Tuning	50-150 pf ±5%	500 V	CYFR Corning
C_6	Capacitor	Coupling	240pf ±5%	500 V	CYFR Corning
C_4	Variable Capacitor	Bias Adj.	0.8 to 4.5 pf	500 V	JFD 26-01011-1
T_1	Transformer	Coupling	Bridge	200 KC	Bell 26-01523-1
R_1	Resistor	Quad. Adj.	≅ 301 ohm ±1%	1/8 W	IRC XLT — Per MIL-R-55182
R_2	Resistor	Bandwidth Adj.	≅ 30.0 K ohm ±1%	1/8 W	IRC XLT
R_4	Resistor	Collector Load	499 ohm ±1%	1/8 W	IRC XLT
R_5	Resistor	Emitter Load	18. K ohm ±1%	1/8 W	IRC XLT
R_3	Resistor	Feed Back	330 K ohm ±1%	1/4 W	Allen Bradley RCR07. Per MIL-R-39008
R_6	Resistor	Bleeder	22 M ohm ±1%	1/4 W	Allen Bradley Ohmite RC07 Per MIL-R-39008
Q_1	Transistor	NPN	2N930	0.30 W	TO-18 Fairchild Per MIL-S-19500/253
Q_5	Capacitor	Collector Decoupling	1.0 ufd ±10%	50 V D.C.	Kemet KGLJ50KMS CSR13G105KP Per MIL-C-39003/1



PART #26-00565-1

UPPER BOARD

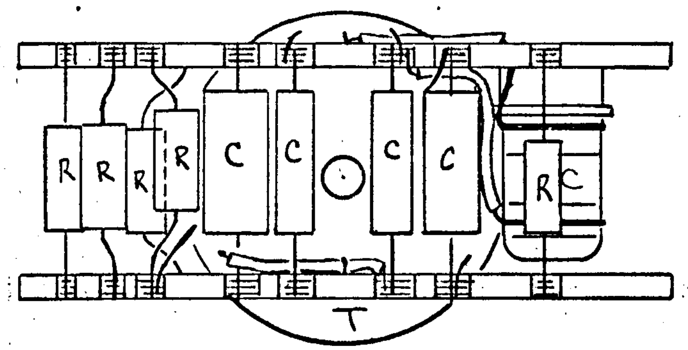
FIGURE 17E



Part #26-00568-1

LOWER BOARD

FIGURE 18E



TYPICAL CONSTRUCTION TO ILLUSTRATE PACKAGING TECHNIQUE

FIGURE 19E

2.1.9 Discrete Component Selection (Refer to Schematic Drawing, Figure)

2.1.9.1 Capacitors

C_1, C_2 - Fixed Bridge Capacitors

Because these two capacitors constitute one half of the sensitive capacitance bridge, these capacitors must be extremely stable devices. They must have low dissipation factors and must have good temperature characteristics.

The type of capacitor selected is Corning Glass CYFR per Specification J951 inspection level B. This is a glass capacitor of fused monolithic construction of proven glass dielectric and conductive elements. A glass to metal seal is provided on the ends of the unit to provide complete environmental protection to the element and to the wire lead connection.

The temperature coefficient is 140 ± 25 PPM/°C. At 100 KC, temperature coefficient varies with temperatures from +115 PPM/°C at -55°C to +165 PPM/°C at +125°C. At any given temperatures, T.C. will not vary from the curve by more than 5 PPM. Capacitance drift is less than .1% or .1pf, whichever is greater.

C_3 - Tuning Capacitor

This capacitor is used to tune the primary of the pickoff transformer to resonance. It must be stable, and the size must be minimum. Here again, the capacitor type is Corning Glass CYFR per Specification J951 inspection level B.

Both of the aforementioned capacitors are similar to those which appear on the JPL Approved Parts List.

2.1.9.2 Resistors

R_1, R_2, R_3, R_4, Fixed Resistors

R_3 and R_4 are used primarily for D. C. biasing; R_1 is a quadrature resistor; R_2, a bandwidth resistor. These resistors are all high Rel type which conform to MIL-R-55182A inspection level B. They are also Q. P. L.

The resistor is a metal film type which also meets the specification as outlined in MIL-R-10509D. The main reasons for selecting this component were that it met all the circuit requirements, wattage, stability, and the predicted failure rates at a 60% confidence level. From a packaging point of view, it was necessary to have a component, which not only met the circuit requirements, but also had the proper physical size. There are dimensional limitations on the resistor in order to achieve the high density package. The circuit, as packaged, will not allow for a resistor diameter to exceed .160 inch. These dimensional limitations have been met with the IRC-XLT Resistor.

2.1.9.3 Capacitor - Variable

Variable Capacitors Required to Electrically Torque Final Accelerometer Assembly;
This is a capacitor which was specifically designed for Bell Aerosystems Company by J. F. D. Electronics, Brooklyn, New York. Bell has used similar types in past as well as present programs. This capacitor is purchased per Bell Spec. Control Drawing Number 26-01011-1 Variable.Capacitor.

The primary concern with this capacitor is stability of setting and temperature coefficient. Similar type units have been qualified for NASA by Collins Radio with intended use on Apollo.

Capacitors of this same general type without sterilizable requirements are presently being used in our Model VII Program.

2.1.9.4 Decoupling Capacitor C_5

The purpose is to decouple the collector of the Unity Gain Pre-Amplifier. The capacitor selected for this is a Kemet 1.0 ufd rated at 50 VDC (Type KG).

Mfg. Part Designation is: KGLJ50KMS Similar to that which appears on the JPL Approved Parts List. MIL Part No. CSR136105KP Per MIL-C-39003/1

2.1.9.5 Transistor

An NPN 2N930 transistor was selected as the Pre-Amp. semiconductor. It was selected because of its proven reliability and because it appears on the JPL Approved Parts List.

Other transistors were considered, such as the Solitron MHM 1107 and the 2N997, which are high gain low noise darlincton configurations. These have the advantage of a much lower output impedance as seen at the output of the accelerometer; typical output impedance would be approximately 25 ohm with a collector current of approximately 6.0 ma. Whereas, the typical output impedance with the 2N930 would be somewhere less than 500 ohm.

2.1.9.6 Resistor Feedback R 330K Ohm

The resistor is a molded composition resistor procured from Ohmite or Allen Bradley. The resistor type is a RCR07G which meets and is certified to the specification as outlined in MIL-R-39008 (RCR07, RCR20).

The basic reason for the selection of the component is its small size and high ohmic value. In order to facilitate the same value resistor in a metal flim type construction, the entire bonnet would have to be re-packaged, including an increase in overall height. This part is similar to the 1/4 watt carbon composition resistor found in Table II (Spacecraft preferred components) of the JPL APPROVED PARTS LIST.

2.1.9.7 Resistor Bleeder R6 22.0M Ohm

The selection of this particular type, RCR07 per MIL-R-39008 (RCR07, RCR20), was made primarily for its small physical size and its high ohmic value. The additional background information of paragraph 2.1.9.6 also applies to this component.

3. PROGRAM SCHEDULE

The original program plan is contained in Bell Report Number 60002-440-1, Proposal for Design of a Sterilizable Accelerometer, Supplement No. 1, pages 18 and 19. This program schedule was established under the assumption that experimentation could be performed on three functional accelerometers. Actually only two mechanical assemblies and one functional electronic assembly have so far been available.

Only one bonding cycle for the evaluation of an adhesive in the spring-to-support joints of a functional accelerometer, namely for the evaluation of the Ablecast 147-1 epoxy, was completed at the end of the seventh monthly reporting period. The bonding cycle for the evaluation of the Bondmaster 620 epoxy had aborted. According to the original schedule, three bonding cycles should have been completed by then. It was felt, at this point, that it would be helpful to issue a revised program schedule clarifying how the program plan was expected to develop. This program schedule was issued in conjunction with the monthly technical progress report No. 7 covering February 1967. Early in March 1967, the program suffered a setback due to the failure of the Formex insulated magnet wire in accelerometer M-225. This failure caused a slippage of about three weeks in the schedule established for the mechanical assembly. Since the program schedule contains practically no allowances for contingencies, it is not believed that this slippage can be recovered.

In the area of the electronic assembly a similar flat statement can not be made. It is true, that the final electronic assemblies were not built as scheduled because not all of the parts were available. However, one additional functional electronic assembly, basically of Model VII design, was supplied and the already available electronic assembly was modified to improve its chances of meeting the temperature sterilization environment, so that accelerometer testing was not held up. All discrete components needed for the building of the final electronic assemblies were either available or on order at the end of the present quarterly reporting period; delivery, where applicable, was promised by 15 May 1967.

JPL Contract Number 951492
Sterilizable Accelerometer Development Program

Revised Program Schedule for March through August 1967 - First Page

	March	April	May	June	July	August
1. Mechanical Assembly						
1.1 Evaluation of Scotchweld EC 2258 in Accelerometer M-225						
1.1.1 Rebuild Mechanical Assembly, attach Electronic Assembly	1 ↔ 8					
1.1.2 Preliminary Tests and First Cycle of Flip-Flop Soaks	8 ↔ 21					
1.1.3 Attach Dummy Electronic Assembly, Seal Unit, Temperature Sterilize	23 ↔	7				
1.1.4 Attach Functional Electr. Ass'y. Second Cycle of Flip-Flop Soaks		10 ↔ 20				
1.2 Evaluation of Replacement Materials in Accelerometer M-225		21 ↔ 25				
1.3 Evaluation of Further Replacement Materials	↔	↔				
1.4 Design Freeze of Mechanical Assembly			▲1			
1.5 Build Final Mechanical Assembly						
1.5.1 Build Subassemblies Unaffected by Design Changes.	↔	↔				
1.5.2 Build Balance of Subassemblies		1 ↔	11			
1.5.3 Build Complete Mechanical Assembly			▲12			

JPL Contract Number 951492
Sterilizable Accelerometer Development Program

and Quarterly Technical No 3 - Page 2

Revised Program Schedule for March through August 1967 - Second Page

	March	April	May	June	July	August
2. Electronic Assembly						
2.1. Transformer Investigation						
2.1.1 Build 4 Transformers	←	→ 7				
2.1.2 Perform Standard Tests on Three Transformers		7 ← → 11				
2.1.3 Test One Transformer Before and After Temperature Sterilization		11 ←	→ 1			
2.2 Assemblies with Mfg. Equivalent Components						
2.2.1 Build Two assemblies		11 ← → 12				
2.2.2 Perform Standard Tests on Both Assemblies		12 ↔ 14				
2.2.3 Temperature Sterilize One Assembly and Test Same		14 ←	→ 1			
2.2.4 Mate one Assembly to Mech. Ass'y. Sterilize 60 hrs. and Test		20 ←	→ 27			
2.3 Final Assembly with JPL Approved Parts (where available)						
2.3.1 Build Final Electronic Assembly			1 → 3			
2.3.2 Simulator Test of Final Electr. Assembly			3 ↔ 5			
2.3.3 Prepare for mating with Final Mechanical Assembly			▲ 12			
3. Final Product						
3.1 Mate Final Electr. Ass'y. with Final Mech. Ass'y. Seal Unit			▲ 15			
3.2 Test of Sterilizable Accelerometer			17 ←		→ 22	
3.3 Delivery to JPL of Tested Accelerometer					▲ 26	